THE DESIGN - PRODUCTION INTERFACE IN THE UK MECHANICAL ENGINEERING INDUSTRY

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SYNOPSIS

This thesis reports the results of a novel investigation of the management of product design in the UK mechanical engineering industry. The research examined the management of product design, specifically the relationship between design and production functions, in the mechanical engineering industry as a whole. It measured the design performance of firms as measured by the amount of design modifications carried out after drawing transfer to production and the number of standard components in a design.

A novel and unique two-pronged research methodology was developed. This consisted of a national survey of the UK mechanical engineering industry and a set structured interviews. The survey was a random, and thus representative, postal questionnaire survey of 860 companies. A response rate of 13% was obtained. Two sets of case studies were undertaken: on firm's use of CAD and on design management. The structured interviews, of pairs of closely matched firms, were linked to the survey by an analytical bridge - design performance, as measured by design modifications after drawing release to production.

Theoretically the study identified three possible solution approaches to bridging the design - production gap: methodology, technology and organisation. It was concluded that methodology solutions (DFA, QFD, BS 5750) had little use and impact in industry. Second, management's approach to, and use of, methods for design freeze, generational design and standardisation was the key factor in producing better performance. Technology (CAD) as a solution to the design - production interface was limited, due to its low diffusion, use for 2D drawing and technological limitations.

It was shown for the methodology and technology solutions that organisation was the key - the better performing companies not only used certain techniques and technologies but used them better. These companies had an integration culture and a pro-active management. The complacency of firms was jolted by catalysts - TQM, commercial flops and the recession. It is concluded that firms will only improve their design - production integration when forced to by a catalyst. Simultaneous engineering, another catalyst, addresses itself directly to product design, and is thus recommended as the way to improve the competitive position of Britain's mechanical engineering industry.

Key Words: Management of Product Design, Design - Production Integration, Design & Production Functions Relationship Between, Mechanical Engineering, Product Design, CAD, CAD/CAM.

DEDICATION

For my mother and father.

Dedicated to my teachers and students.

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CHAPTER 1.

INTRODUCTION

This chapter sets the scene for the research - introducing the research project, its origin, aims, scope, and context. A brief review of the methodology and limitations of the research is also included. The chapter explains the structure of the thesis and how this related to the research project. It also presents a summary of the main findings of the research.

The research concerned the design - production interface in the UK mechanical engineering industry. That is, the interaction between the design and production functions of mechanical engineering firms for the introduction of new products. It is thus concerned with the management of the product design process. In contrast to other studies of product design it was particularly concerned with the consideration given to the manufacture of a product when it is designed. It is this concern with production and its interaction with design that makes this study unique. Further, the adoption of a novel, two-pronged, research design is also unique. This consisted of a national survey of the UK mechanical engineering industry and eleven follow-up structured interviews. The linking bridge between the survey and the structured interviews was design performance, as measured by the amount of modification and standardisation of a design. The structured interviews were rigorously structured to compare matched pairs of poor and good performing companies as indicated on these measures. This, in itself, is also an unusual approach in studies of product design. This allowed the crucial factors influencing a firm's performance to be determined.

1.1 Origin

This thesis originated in a research project set up by my supervisor, Dr Kulwant Pawar, at the then Wolverhampton Polytechnic in 1988. The project was intended to investigate the working relationship between design and production functions in UK manufacturing industry. Dr Pawar has an academic and industrial background in production engineering and completed his own PhD on the design - production interface in 1985. This was based on twenty case studies of manufacturing firms in the West Midlands. It was from this work that this research project was designed to follow on from. The research proposal was approved by the Research Committee of Wolverhampton Polytechnic and support for the employment of a research assistant for three years was given. When the post was advertised in the press I was intrigued and applied (and got the job).

I am an engineer by training - an electrical / electronic one, with a heavy emphasis on computers both hardware and software. I started my engineering training straight after I left school, embarking on an engineering programme at my local Technical College culminating in the award of an O.N.D. in Technology (Engineering). In 1980 I entered Aston University on a four year sandwich degree course in Electrical and Electronic Engineering. During the degree I worked in industry, first with Siemens Ltd and then with the CEGB - in both companies I worked in the design department. Most of my work during this time was to do with the design of hardware and software for microprocessors, and the writing of computer programs (particularly user friendly ones).

It was during this time in industry that I first came into contact with the discipline of design, and actually experienced it myself in practice. This whetted my appetite for the further study of design. However, my experience in industry taught me that the main problem in engineering was not the technology but the people aspect. This was especially brought home to me at the CEGB. I worked in the Design and Construction division of the CEGB at Barnwood in Gloucester. The building I worked in was devoted not so much to the design of power stations (this was actually done by the subcontracting firms) but rather the overseeing and management of the design process. I decided that management was a more important and interesting subject to study. I, therefore, left the technology behind me and embarked on a conversion M.Sc at Imperial College in London (from technologist to management).

My experience at Imperial opened my eyes. It never occurred to me that organisations, and the way that they worked, were a subject worthy of academic study - they do not fit into the normal academic disciplines. This insight that organisations can be studied, designed and improved has become a guiding light for me. It was thus fortuitous that the project at Wolverhampton came along just when I was looking for a job. It was especially good as it utilised my interests and skills in engineering and technology and combined this with management and, of course, design.

I started work on the research project in October 1988. It took me six months until I had 'found my own way' into the project and began to formulate my own ideas and approach. This of course, was worked out with both my supervisors, Dr Pawar and Dr Jacqueline Lewis (then of the Polytechnic's Economics department). I wrote up my researches and ideas into two reports (the "Sixth Month Report", Riedel, 1989a and "The Distribution of CAD/CAM in UK Manufacturing Industry" Riedel, 1989b). These two documents in combination with the research team's background meant that the project took as its principal focus management - the management of the design - production interface - rather than the engineering or technical aspects and also excluding the marketing aspects. Both of these latter approaches are well covered in the literature. However, the management, co-ordination and particularly the integration of production considerations into the design process is under-represented. This determined the aims of the research project.

1.2 Aims

The research had three aims:

1) To investigate the nature of the working relationship between design and production functions in the UK mechanical engineering industry.

   This relationship was broken down into four aspects, or themes:

   a) the product specification;

   b) the organisation and co-ordination of design and production functions;

   c) the consideration of production aspects;

   d) the role of CAD/CAM.

2) To analyse this relationship in terms of product design effectiveness as measured by:

   a) the amount of modification carried out to designs after drawings have been transferred to production

   b) the percentage of components in a design which are standard.

3) To attempt to produce a general framework for the application of

recommendations for improving product design appropriate to different types of companies.

1.3 The Problem

Previous research has shown that the majority of the costs of manufacturing a product are determined during the design of the product. Thus, in order to effectively manufacture products for competitiveness, companies must pay attention to the manufacture of the product when it is designed. The design - production interface is an important part of the process of introducing new products. To be able to introduce new products quickly depends on being able to design the product quickly and rapidly manufacture it (Riedel & Pawar, 1991). It also means minimising the time taken to produce new tooling and other ancillary production equipment, and to efficiently utilise the resources of machinery, money and staff. Primarily, it requires that the new product be easy and efficient to manufacture. The ease of manufacture of a product is determined when it is designed. Reducing the number of components greatly aids manufacture. The number of components is, of course, determined by the design. Also reducing the number of modifications made to a design when it is introduced to manufacturing saves both time and cost.

1.3.1 Design Costs

Research has shown that the cost of manufacturing a product is fixed when it is designed. There are two costs to be conceptually clear about. First, the costs of design - the cost of running a design department and the associated cost of producing individual designs. Second, the product's manufacturing cost - this is the cost to manufacture the product. The majority of the latter are determined during the design stage. Whitney (1988) cites a study at Rolls-Royce which showed that design determined 80% of the final production cost of 2,000 components. He also cites General Motors' executives claiming that 70% of the cost of manufacturing truck transmissions is determined in the design stage. Swift (1987) cites the 1983 study by Andreasen et. al. of the apportionment of production cost to the departments of firms. This study showed that most of the important decisions concerning product manufacture and assembly are taken during the design process. Further, it showed that 70% of a product's cost is determined during the design phase, and only 20% during actual production, see Figure 1-1. Port et.al (1989) quote Rodney MacDow, a director of Prime Computer (owners of Computervision the CAD company), as stating that 70% to 90% of a product's cost is locked in during the design phase. Moreover, changing a design after it reaches the shop floor costs ten times as much as catching it on the drawing board - and 100 times as much if the change is made midway through the production cycle (Charney, 1991). Charney also reports that 80% of a product's cost is committed during the design phase whereas design only absorbs 8% of incurred costs (see Table 1-1).

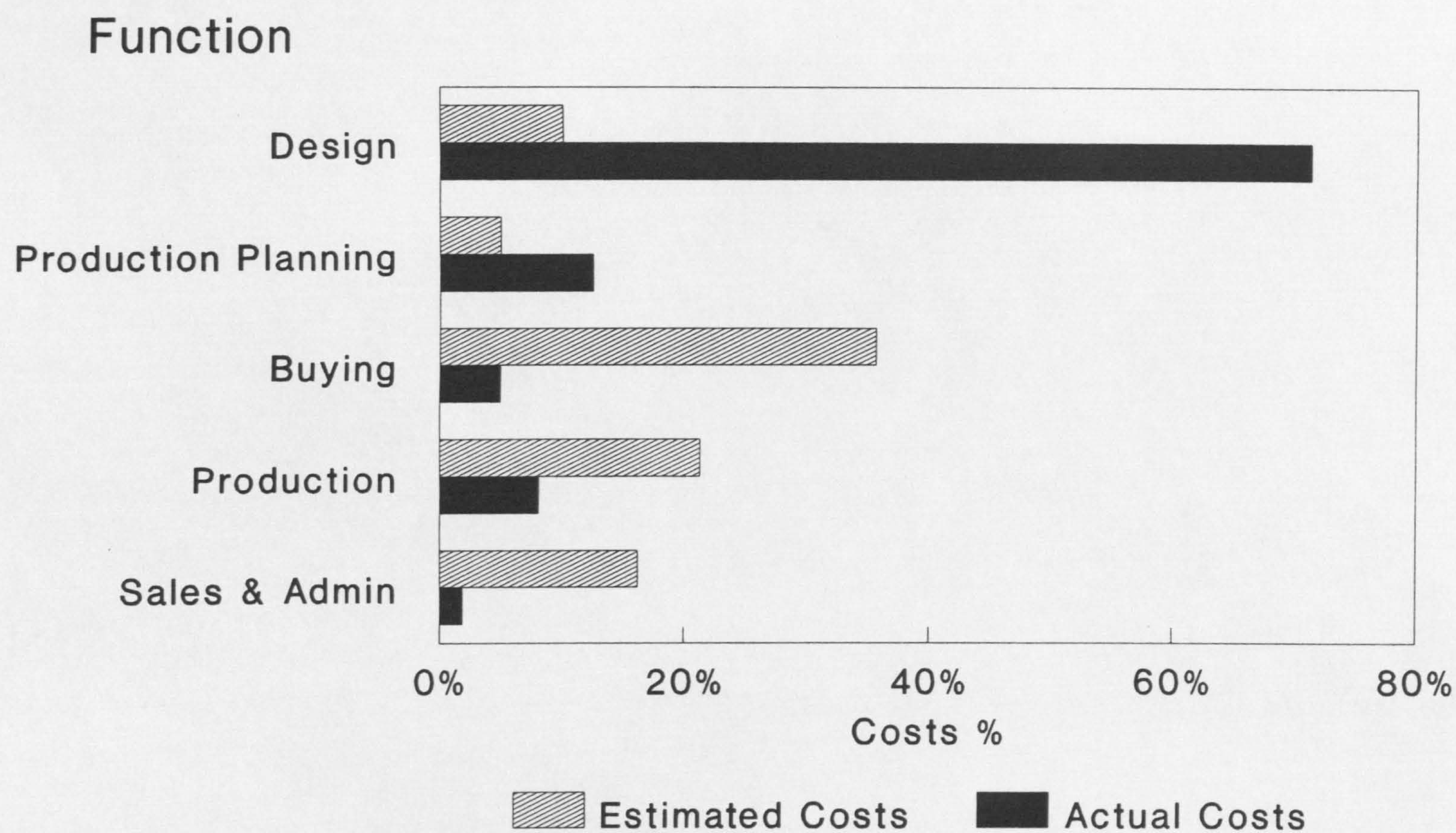
Table 1-1: Costs & Design Stages

Design Stage	Cumulative Cost Incurred	% Total Costs Committed
Conception	3-5	40-60
Design	5-8	60-80
Testing	8-10	80-90
Process Planning	10-15	90-95
Production	15-100	95-100

Source: Charney (1991).

Obviously it follows that improving the design of products to take account of their manufacture can radically affect the economics of producing them. Considering which manufacturing operations account for product cost, Swift (1987) claims that assembly often accounts for over 50% of total costs. Tidd (1991) quotes results which show that assembly typically accounts for over two-thirds of manufacturing costs. This is particularly significant because the vast majority of assembly work is done manually. The OECD estimated that just 5% of all assembly work was fully automated in 1983 (Tidd, 1991). In automobile and electrical sectors around 70% of all direct labour is in assembly (ibid). Assembly in automobiles has grown in significance - accounting for a quarter of manufacturing time in 1980 and over a third in 1986 (ibid). However, direct labour in assembly accounts for only 5-10% of total costs, hence automation may be counter-productive if it increases indirect labour and overhead costs (ibid). More effective assembly would result in time and cost savings. The only way to improve assembly, whether manual or automatic, is by designing the product to be easy to assemble. Similar considerations apply to other manufacturing processes such as machining, casting, forging, plastic moulding etc. Hence, the determination of manufacturing costs during design places the emphasis upon design and the transmission of information from manufacturing to design during the design process.

Fig 1-1 Design & Product Cost



Source: Swift (1987)

1.3.2 The Problem of the Design - Production Interface

The interaction between design and production required during the design of a new product is problematical (Pawar & Riedel, 1990). The worst case example of this would be that the designers could design a product that the company was unable to manufacture, or more likely to ineffectively produce. Design and manufacturing personnel are usually located in physically separate departments, sometimes even geographically separate. Both designers and production engineers have their own disciplines and culture, which can militate against effective communication. Designers usually have more status and influence within firms than production personnel. This disparity means that the key input of production into the design of the product is hampered. There is also the question of organisation of the company and of the process of introducing new products. If the company organisation keeps designers and manufacturing separate then the scope for mutual interaction is limited. If the production personnel are not included in the product design team their insights and knowledge cannot be applied to tuning the design for manufacture. Communication between design and production personnel is thus an issue. A continual interaction between design and production personnel is required in order to effectively introduce new products (Riedel & Pawar, 1993a). Thus how to bridge the gap and span the interface between design and production is a crucial issue. The research reported here has been designed to address this.

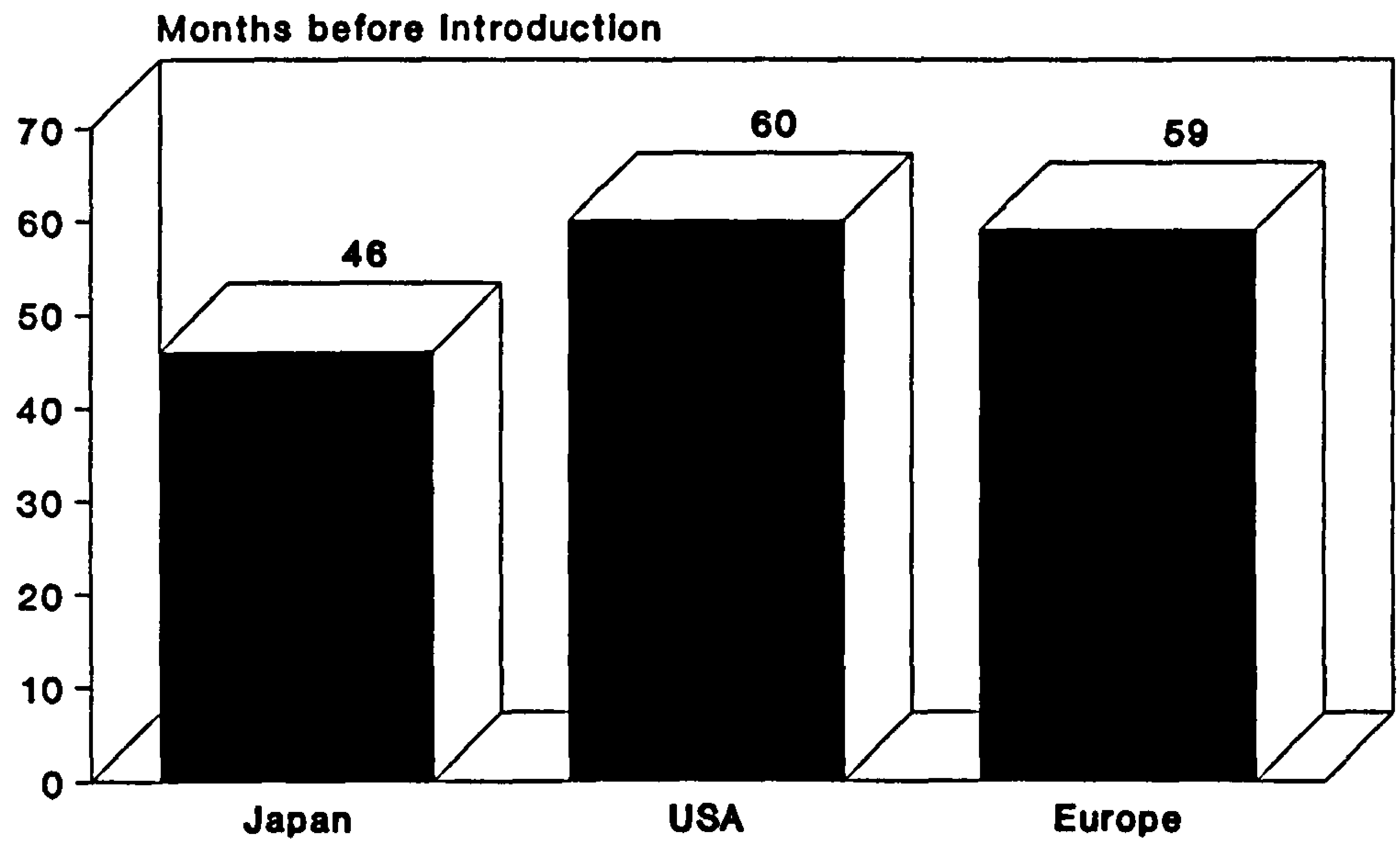
The design - production interface was divided up into two parts (further elaborated upon in the theory chapter 2, Section 2.5), the product specification - where a written specification of the product is drawn up - and the product design process - during which the product moves from design to manufacture. The product design process is further divided into three themes: 1) organisation and co-ordination of the process, 2) the consideration of production aspects during the process and 3) the role of CAD/CAM. These four themes were used to structure the discussion of the theory and results (see Figure 1-4 on page 27). The research investigated how each of these impacted upon the effective design of new products. The argument of this thesis is that the earlier, and the more, that production aspects are considered during the design process the better outcome - in terms of product design effectiveness (as measured by design modifications and standardisation of components).

1.3.3 The Issue Now

Over recent years the issue of international competitiveness has assumed great significance. Britain's decline relative to its competitors has led to a plethora of reports being published on the causes and solutions. Design has been identified as a crucial weapon in the struggle to regain competitive edge. Reports by the National Economic Development Office *Product Design* (1979); the Department of Trade and Industry: *Design to Win* (DTI 1989), *Profits by Design* (DTI, 1991a), *Managing the Financial Aspects of Product Design & Development* (DTI 1991b); the Design Council: *Design and the Economy* (Roy et.al 1990), *Profit by Design* (Service et.al 1989); the promotion of simultaneous engineering by the DTI (Mortimer & Hartley, 1991); the Joint Design Council - Engineering Council *Attaining Competence in Engineering Design* (1990); have all urged industry to improve its product design in the campaign to rescue Britain's flagging industry. Smith in reviewing the UK's manufacturing performance stated "The UK undoubtedly lags behind major competitors in the amount of resources devoted to R&D - though not just in the high research intensity categories" (1986, p16). Further, "Raising productivity in ways which enable existing products to be manufactured more cheaply is desirable across the board, but the UK's position as an advanced industrial country can be maintained only through the development of new products - satisfying the needs of new markets, embodying new technologies, or offering attractive new and improved designs" (ibid). However, these official reports have only addressed the front-end of the new product introduction process - product design. What is missing is the role and importance of the design - production interface. Both the improvement in productivity through ease of manufacture and new product introduction, require the effective interaction of design and production functions.

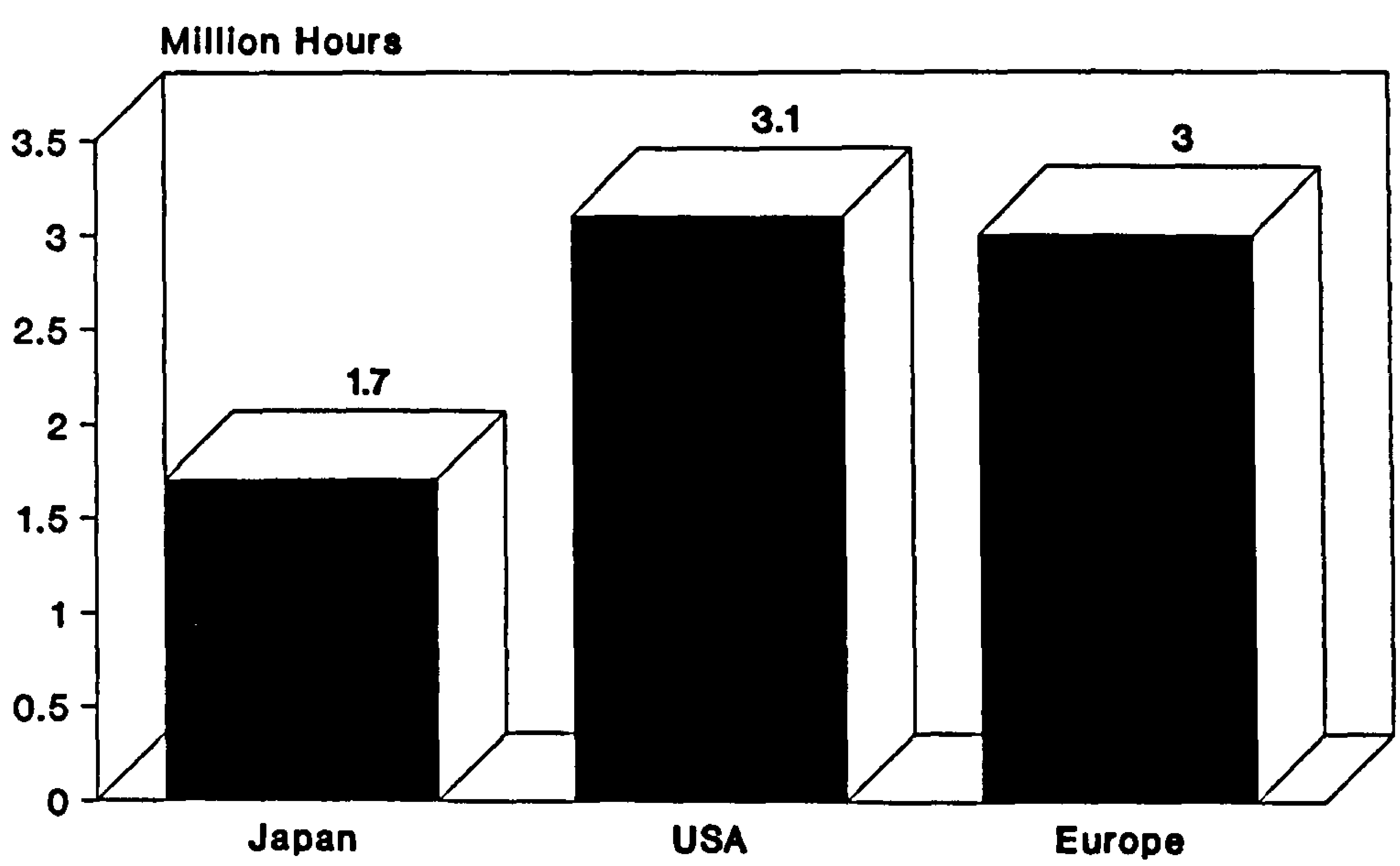
The effectiveness of new product introduction is a key competitive capability of companies. Central to this capability is the relationship between design and production functions (Pawar 1985, Bower & Hout 1988, Gomory & Schmitt 1988, Riedel & Pawar 1991). Two benefits arise from this capability (Bower & Hout, 1988). First, being able to shorten the lead-time for the introduction of new products and thus achieving a competitive edge over other firms. Second, due to the shortened lead-time the product can be improved over each successive introduction resulting in a technological lead over competitors. Key to the ability to introduce new products effectively and within a short time period is the relationship between the design and production functions of companies. The work of Clark & Fujimoto (1991) showed that Japan introduces new cars 25% sooner than the United States and Europe, and that they spent 44% fewer hours doing so (Figures 1-2 & 1-3).

Fig 1-2 Automobile Development Lead Time



Source: Clark & Fujimoto (1991)

Fig 1-3 Automobile Engineering Hours



Source: Clark & Fujimoto (1991)

This is echoed by Cox & Kriegbaum's (1989) study of industrial strength, "British firms have since the early 1970s invested less than their competitors in Germany, the US and Japan in the research, design and development of new products. It is to this 'intangible' investment in R&D to produce high quality, innovative products, more than tangible investment in plant and machinery to increase productivity and lower costs, that the competitive success of German and Japanese industry is attributable". There is thus a large competitive gap between Europe and Japan. To reduce this gap requires the addressing of the design - production interface, if lead times are to be reduced and resource use minimised. Having formulated the problem the question is what should the scope of the research investigation be.

1.4 Scope

The research project was intended to have a general focus in order to complement the existing literature. Most research on product design is based on case studies of a small number of firms. This has the limitation that the recommendations for better product design apply only to a select number of firms - those similar to the research case study firms. These many case studies of design cannot possibly tell every company in the country how to best design their products. Second, no information is provided about the practice of product design across industry as a whole. The project was structured to have a general focus which would enable us not only to say what was successful but also which type of company could use that method to be successful.

Initially, the project was intended to investigate the interaction between design and production functions in the UK manufacturing industry. This is obviously a rather big area - manufacturing covers several industries. Thus the electrical and mechanical engineering industries were chosen (somewhat naturally enough given our backgrounds). This would enable us to compare the practices in two quite different industries and draw some important conclusions. It was also in tune with the aims of the project and our desire to maintain a general focus to the research. It was decided, however, that covering two industries would be too much work and, therefore, only the mechanical engineering industry should be studied. The next question is how will the study be carried out.

1.5 Research Design

The empirical research consists of two complementary studies. First, a questionnaire survey of a random sample of UK mechanical engineering firms. Second, a set of follow-up structured interviews. The general focus of the research meant that a questionnaire survey was the best method of collecting data. It was decided to carry out a national survey of the UK mechanical engineering industry. This would be done by sending questionnaires to a random selection of mechanical engineering firms. This provided a representative sample of UK mechanical engineering firms. The questionnaire was mailed to senior (director) level management of each firm. The addresses of firms were obtained from the computerised FAME database compiled by Jordans of London (a City business analysis firm). From this list the most recent data was extracted providing a sampling frame of 1,971 firms. This was then used to construct the final sample of 860 firms. A response rate of 13% was achieved. Responses covered a wide range of products, establishment employee size, region and turnover. Negative responses were due to the inapplicability of the questionnaire to the mailed firms and not to faults in the research design or survey methodology.

The structured interviews were structured in the following way. It was intended that five or six structured interviews be undertaken as a follow up to the survey. These would allow the investigation of issues which were identified as important or interesting from the survey findings. This interaction between the survey and structured interviews forms the second claim to originality of the research. It turned out that CAD emerged with an interesting finding - firms using CAD had higher modification than firms not using CAD. This was contrary to our expectation and would have the implication that CAD, rather than improving the design process was actually hindering it! Thus, six structured interviews were set up to investigate the impact of CAD. The structured interviews were structured in a framework in order that the cause of the high modification could be identified. Hence, CAD using firms were paired: similar firms with high modification were compared to firms with low modification. In all other respects, the companies needed to be identical, or closely matched. The reasons for their difference would thus become clear in the comparison of the firms. The process of selection of firms produced five firms (one match could not be made) and three products - two firms for each product. The chosen products were conveyors, machine tools and railway brakes. This produced a two by three matrix allowing comparison between pairs and across firms (making different things). The structured interviews would also gather in-depth data about CAD use by considering the individual firm's experience of CAD use. Also the firm's experience on certain issues (2D/3D drawing, sophisticated uses of CAD) can be contrasted with some of the survey findings. This allowed some of the ambiguity, arising from the generality, of the survey to be resolved. It would thus bolster the validity of the survey and hence the research findings. A similar structure was devised for the structured interviews which investigated design organisation and co-ordination and consideration of production. The selected products were agricultural machinery, air conditioning and pumps.

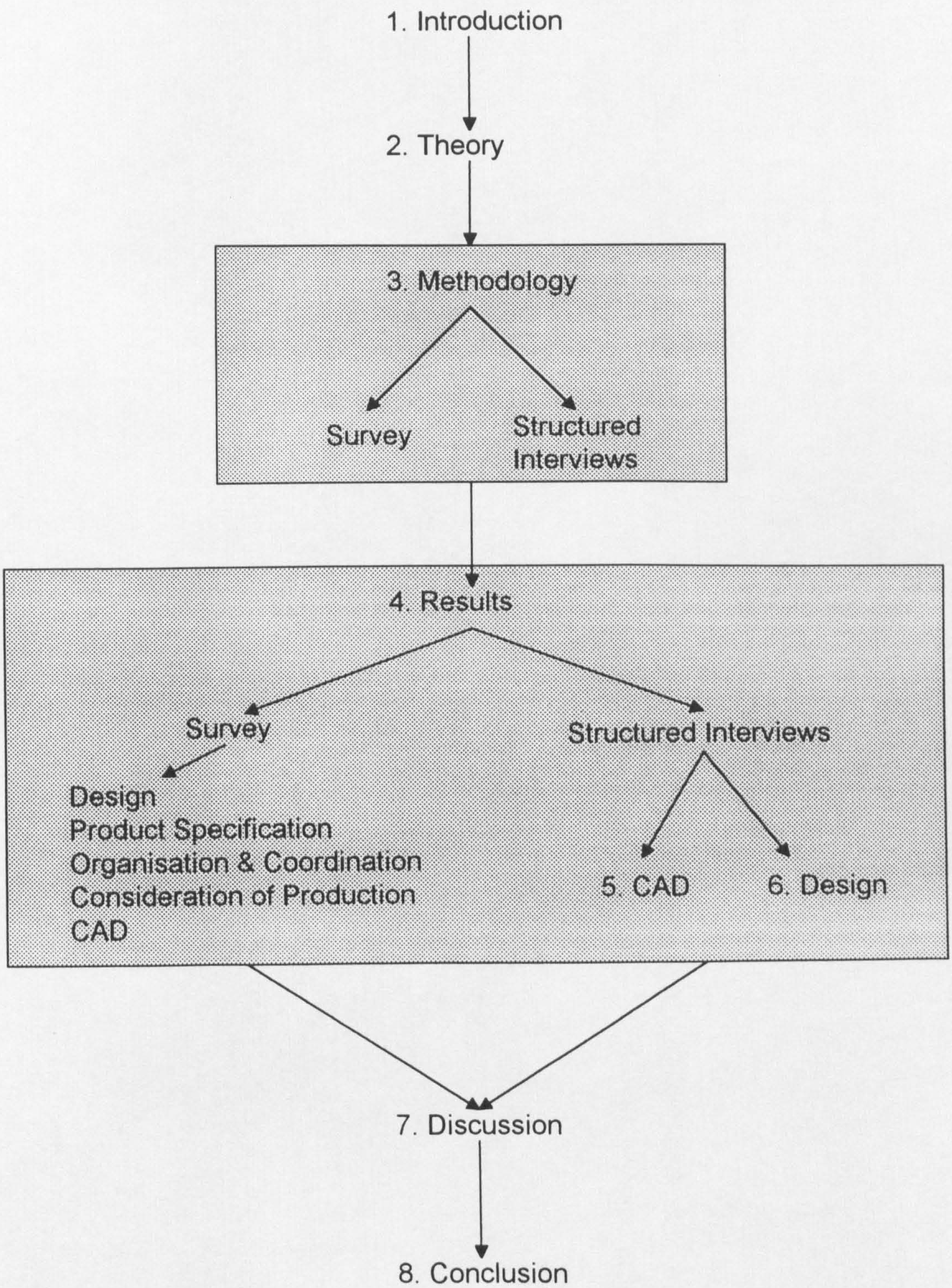
This research design is unique - the complementing of a national random survey with structured interviews has not been attempted before. Also the bridging of the survey into the structured interviews through the use of a measure of design performance - modifications is novel. The structuring of the structured interviews is also rigorous and provides and excellent method for maximising the validity of the research findings. This research design, therefore, provides one of the claims to originality of the research.

1.6 Limitations

The limitations of the research arise from the adoption of a self-administered questionnaire as the research instrument. Such a questionnaire has to be kept short in order that potential respondents are not put off filling it in. This limits the depth of information that can be probed. Second, questions have to be framed to which there is a ready response, and which does not involve the respondents referring to documentation. The second phase of the research work - structured interviews - will overcome some of these problems. A questionnaire also has the disadvantage that it is one-shot, it takes a snap shot of the situation at one point in time. This presents a static view of an ever changing reality. Even when a questionnaire is repeated after a time interval a dynamic picture of what is going on does not emerge.

A further limitation of a questionnaire is the lack of explanatory power. As only one set of data is obtained from each company at a fixed point in time no information is obtained about how the company arrived at its current position or why. This means statements about causality are limited. One cannot say successful firms do x, if you do it as well you will be successful, because the cause of company success <u>may not</u> be dependent upon x, but on other factors - such as good financial management etc. A questionnaire cannot unpick this maze of multi-causality, it can only draw inferences of the kind: firms using x were (statistically) more successful than firms not using x. Nothing can be said about what one also needs to do as well as x.

Figure 1-4 Stucture of the Thesis



The structured interviews also have the limitation of being one-shot, not being repeated or followed-up. The static nature of the findings is thus not altered. This means that many things can happen - such as successful firms can stop being successful after the investigation. This obviously would invalidate some research recommendations. Structured interviews do have two major advantages. First, they allow the collection of very rich in-depth data about specific companies and their activities. This is useful in itself but also aids the process of explaining success (or failure). Second, they provide more contextual data about the company that can aid in determining causation. Thus the company's financial, market position etc can be examined for causal influences upon the firm's success or otherwise. In this research, however, one-day visits were made to companies. Data was not gathered over a period of time. Hence, the determination of causality is still hampered. The combination of survey and structured interviews methods did produce some interesting and insightful data into the design - production interface.

1.7 Structure of the Thesis

In reading the thesis it is helpful to keep the following in mind: There are two main parts to the research: the survey and the structured interviews (illustrated in Figure 1-4). The survey part is divided into four themes: product specification, organisation and co-ordination, production considerations and CAD. These themes run right throughout the thesis from theory (chapter 2) to the conclusion (chapter 8). Intersecting each of these themes in the results and discussion are the two performance measures - modifications and standardisation. After the theory chapter follows the methodology (chapter three). Then the survey results (chapter four) and the CAD and design structured interview results (chapters five & six). The Discussion (chapter seven) and Conclusion (chapter eight) follow. The conclusion presents the findings of both parts of the research. It is where the findings of the two methodologies are integrated to produce conclusions and recommendations. There then follows the bibliography and the appendices (A: terminology; B: the survey questionnaire; C: a list of the research project publications; and D: a statistical appendix of microelectronics use in industry). Below is a summary of the main points of each chapter.

The theory chapter (two) consists of a literature review of product design and the introduction of the theoretical framework of the thesis. It starts with a discussion of what design is and the definition of product design employed in the thesis. A review of other studies of design showed a lack of generality, the studies being focussed on narrow products or industries, small sample sizes, geographically limited and an absence of the consideration of production. The theoretical framework of the thesis is presented through reviews and discussion of manufacturing and its impact upon design. Solution approaches to the problem of the design - production interface were grouped into three - methodology, technology and organisation. The conceptualisation of the design - production interface being divided into two parts, the product specification and the design process, was put forward. The various models of the design process were reviewed and the adopted model justified, primarily by its simplicity and limitations of the postal survey research method. The chapter then examines in detail the four-way division of the interface into the four themes of product specification, organisation and co-ordination, consideration of production and CAD.

The research methodology (Chapter 3) provides a review of methodologies of other relevant studies of product design, a full discussion and justification of the two methods adopted, the national survey and the structured structured interviews. The details of the methods are presented along with a discussion of their limitations. The survey methodology part includes a discussion of the coverage and representativeness of the respondent firms. The results of the survey are reviewed in the following chapter four - survey results - which was presented using the four themes. The main findings are summarised below.

1.8 Summary of Findings

The survey showed that the overwhelming majority of mechanical engineering firms carried out the design of the products they manufacture. The overwhelming majority of firms carried out engineering design in-house, with a majority carrying out aesthetic design in-house. It was concluded that design was well institutionalised for the majority of mechanical engineering companies. The majority of all firms irrespective of size designed their own products, with only the smaller firms (less than 50 employees) being more likely not to design their own products. The measure of design intensity, new products introduced per year, showed that most firms introduced one product per year. Significant proportions of firms introduced two and three products per year.

1.8.1 Product Specification

The main findings for the product specification were: The majority of firms drew up a product specification. In terms of regional distribution the analysis showed that regional location did not influence firms in compiling specifications. Firms with more than 50 establishment employees compiled product specifications, firms smaller than this were less likely to. Subcontracting was confined to firms with less than 200 establishment employees. The majority of firms compiled a written product specification (55%). Forty two per cent of firms used verbal and written product specifications. Only three per cent of firms used a verbal specification. The smaller firms tended to supplement written specifications with verbal instructions, 15% using verbal only specifications. There was a mild tendency for no specification to be drawn up as production equipment age rose to 30 years old. The process technology used by firms, the type of product (final, intermediate, both or consumer), and the number of new products a firm introduced per year did not determine specification compilation.

Two measures of design effectiveness were used to determine firms' performance. The analysis of the first, standardisation, produced ambiguous results. The other measure of design effectiveness was modification. At higher levels of modification it is better to supplement written product specifications with verbal instructions to reduce the amount of modification. At low levels of modification it is slightly better not to so supplement written specifications.

The most important aspects that firms considered in their product specifications were functional and engineering requirements along with product cost. Fewer than a quarter of firms considered production aspects in the specification. Thus the pulling forward of the design process was not detected by the survey. Only a small minority of firms considered the later, production aspects, in this early phase of compiling the product specification. The majority of firms extensively involved design management, sales, marketing and designers in the drawing up of the product specification. The priority accorded to the involvement of design management points to firms specifying products in wider terms than a purely narrow design or sales perspective. However, the expertise and knowledge of production personnel are not included in the product specifications drawn up by companies.

1.8.2 Organisation & Co-ordination

The most frequent organisation structure in use was simultaneous engineering. Firms were equally split in the use of matrix organisation and integrated product-process design departments. The majority of firms used meetings as the design co-ordination mechanism. Project teams, product champions and ad-hoc consultation/ visits were each in use by nearly a half of firms. Liaison officers were hardly used at all. Project teams were used by firms with more than twenty employees, and especially in large firms. Conversely ad-hoc visits were used more in smaller firms but were still used in large firms. Ad-hoc visits/ consultation was used across the size range. There was a switch in the use of meetings, used more below ten million pounds turnover (ie. small firms), and product champions, used more above ten million pounds. It is concluded that meetings within the framework of simultaneous engineering were the most frequent design - production management arrangements.

Designers, sales, production engineering, production management and design management were the personnel most heavily involved in design - production co-ordination. Involvement was not significantly influenced by establishment size.

The attempt to determine which organisation structures and co-ordination mechanisms gave the best design performance produced ambiguous results. Firms with an organisational structure of integrated product-process design departments performed only marginally better than simultaneous engineering and matrix organisation. Standardisation produced clearer results. It showed that integrated product-process design departments produced higher levels of standardisation than other structures. Simultaneous engineering was shown to be a worse performer on standardisation than matrix organisation. The co-ordination mechanisms of meetings, product champions and project teams again gave only slightly better results. The inclusion of sales personnel was shown to increase firms' performance, whereas marketing did not.

1.8.3 The Consideration of Production

The most important production aspects considered in the conception design stage were product cost, development cost, functional requirements and materials. During detailed design the important aspects were engineering design, styling, standardisation, materials and to a lesser extent production processes. During the prototype stage production aspects were most important. During pre-production labour requirements and production control were the most important aspects. This shows that the manufacturability of the product is not considered until after it is designed. Thus, the effective and efficient manufacture of the product is not given sufficient attention by mechanical engineering firms.

The research found that the design stages of a product's development could be summarised as follows: The conception stage was when the specification of the product was considered, with some attention given to how it fitted in with existing products and components. The detailed design stage was when the practicalities of the design were worked out - ie the "what to make" was designed. The requirements of production were also given some consideration - ie. production processes and assembly techniques. The prototype stage was where the costs of what was being made were honed, still keeping the product within specification. Now production aspects were given full consideration: the "practicalities of production" - how are we going to make <u>them</u>, how many, on which machines and by whom. The pre-production stage was for making the products and refining the process of making them. Production was focussed on making the products and their quality.

The research found that production engineering were more extensively involved in the design process the closer it moved toward manufacture. Extensive production engineering involvement during detailed design was confined to a third of companies. Although 60%, or so, of companies had some involvement of production engineering during this stage. By the time the pre-production stage had been reached extensive production engineering increased to 60%.

Design reviews were held by most firms. Production engineering involvement was limited to only having a say in the design. Most firms, however, had good co-ordination between design and production. Factors which hindered co-operation were different expectations, departmental barriers and physical separation. Improvement factors were common expectations, removing departmental barriers and physical closeness. This analysis implies that the differentiation between design and production departments had created a management problem for firms. Thus, management were still trying to understand the interface between design and production and how to manage it.

It was found that the prototype design stage was pivotal - where the balance shifted from design aspects to production aspects. Companies' current practice is thus to consider the manufacture of a product after it has been designed. This has ramifications for the efficiency and speed of manufacture of a product. Production engineering were involved the closer a product moved toward manufacture. Companies should endeavour to consider the production aspects of machinery, labour requirements and plant in the detailed design phase. There is also scope for production to be considered in the conceptual design stage, which at the moment concentrated on the specification of the product.

1.8.4 Computer-aided Design

The results for CAD of the survey of the UK mechanical engineering industry, were found to be consistent with previous research. It was found that 58% of surveyed companies used CAD. This, and the regional and establishment size distribution of users were in agreement with previous studies. User firms were concentrated in the South East and West Midlands regions and in the medium and, particularly, large sized establishments. Other characteristics which were found to determine CAD use were: turnover (above two million pounds) production equipment age (less than five years old), process technology (one-off and batch had CAD but not mass/ flow line) and product type (final and intermediate, but not consumer).

Importantly, the survey confirmed the hypothesis that CAD was mainly used for drawing, and in particular 2D drawing, for the industry as a whole. The percentage figures reported for 3D wire frame and solid modelling use augur well for firms realising the full ability of CAD, particularly in the future. The size of firm distribution of drawing showed that the "medium" (200+) sized and large firms mainly account for the use of 3D wire frame and solid modelling. These two types of drawing tended to follow the industry establishment size distribution of CAD use, that is increasing with size. Contrarily, 2D drawing is concentrated in the smaller establishments (less 500 employees). The results of the survey for more sophisticated uses of CAD for design analysis and conceptual design were difficult to interpret. They did show that only a minority of firms claimed to use some form of design analysis. The most significant sophisticated uses of CAD were found to be for bills of material and component interference checking.

For CNC machining only a quarter of firms possessed three axis CNC, with the distribution following that of CAD (increasing with size). Most of them were able to simulate machining on the CAD system. Five axis CNC machines were restricted to the large firms.

The analysis of the impact of CAD confirmed the expectation that it is used overwhelmingly during the detailed design phase of design. It also confirmed CAD use during development and its non-use during testing. The consistent use (30% of users) of CAD in the specification and feasibility stages of design indicates that firms are beginning to exploit the full potential of CAD. The achieved benefits of CAD were mostly the straight forward ones of ease of modification and rapidity of design. There was only a marginal improvement in the amount of co-ordination and integration between design and production functions as a result of CAD use. This was underlined by the lack of access to the CAD system by production engineering. Hence, CAD was used by the majority of firms in simple applications of drawing, and the benefits that resulted were ease of modification and rapidity of design. If CAD had been applied to more sophisticated applications there may have been greater gains. The gains from the involvement of production engineering in design and using CAD to improve the manufacture of products would produce significant competitive advantages in terms of quality, cost and time. These, however, remain to be realised by firms.

An important outcome of the survey was the finding that CAD had increased the amount of modification carried out to designs after they had been transferred to production. This, when taken together with 30% of firms using CAD in the production stage of product design and the ease of modification benefit demonstrates that firms are changing designs while they are in production. Two propositions follow from this. First, that these modifications during production have a detrimental effect upon the efficiency of manufacture of products, costs, and lead and delivery times. If this is so, CAD far from enhancing a firm's competitive position (presumably the reason for the investment in CAD) can actually harm it. This outcome would be contrary to the expectation of the literature. Or, second, the ease of modification provided by CAD enabled firms to a) improve the product during its manufacture and b) to take account of changing customer needs. This responsiveness to customers would improve the firm's competitive position. This latter proposition would imply that the balance between cost and benefits of design modifications during production has been changed by CAD. The survey did not indicate which of these two propositions was the case. To clarify this structured interviews on firms using CAD were undertaken.

1.8.5 CAD Structured Interviews

The CAD structured interviews showed that the quality of the management of the design process, the degree of standardness of the product and competitive delivery pressures determined the amount of modification carried out during a design's production. Management of the design process was found to be the variable which most determined firms' performance. Key management factors were a design review that vetted the design to determine its manufacturability; producing a sound prototype after which no further changes were made and rolling-up production changes every six months. It can also be concluded that CAD had changed the balance between costs and benefits of design modifications - firms were more effectively able to modify designs when they possessed CAD. They could thus correct manufacturing problems and respond to changing customer needs more efficiently - saving time and money.

On standardisation CAD had not led to an increase of the amount of standardisation of products. Rather, the degree of existing standardisation and management implementation of standards determined the amount. These two were influenced by the nature of the firms' products. The more amenable the product was to standardisation the more standards the firm would have standards. Some products, due to the market the firm met, were non-standard and to increase standardisation would mean losing business and possibly customers. Hence the increase in standardisation could only be achieved against a loss of business - a decision each individual firm would have to make given its own market and business position.

In conclusion the competitive use of CAD means that management must focus on the whole design process rather than the narrow role of drawing that CAD presently performs. This necessitates the inclusion of production personnel into the design process and the implementation of management procedures, and mechanisms, such as design reviews. It is these latter management factors that will determine firm's competitive ability. CAD did have a role in speeding up the design process which allowed firms a leeway in either scrapping designs and repeating the design loop or in modifying designs. This enabled them to improve designs without incurring a time penalty, it did not, however, result in shortened lead-times. It was concluded that the benefits of CAD are prerequisites for competitive strength and not its determinants.

1.8.6 Design Structured Interviews

The comparative analyses of modifications in the design structured interviews showed that a) the more simple a company's product the lower the modification; b) full and lengthy consideration of production during the design process (Alef and Beh case firms); and c) management of the design process is crucial to minimising and improving modifications. These two management factors meant that firms applying them would not only benefit from reduced lead-times and design expense, but also better quality products.

It can be concluded that the amount of standardisation in the design structured interview firms was determined by the following two factors. First, high standardisation was achieved for companies with simple products, narrow product ranges and unchanging product technology. Second, management commitment to total quality management and the consistent and continual attention to production considerations throughout the design process. It was this latter factor which determined that the company with a highly complex and wide product range (Meem Air Conditioning) had as low standardisation as a company with a simple and unchanging product (Alef Pumps).

The usage of standardisation of products as a measure of design performance, while producing interesting results, was not effectively able to distinguish between good and bad performing firms. This was because other factors, independent of management's ability to influence standardisation were at play, notably the simplicity and narrow range of products and the unchanging nature of product technology and market needs. The design structured interviews showed that the key management factors were a design review that vetted the design to determine its manufacturability; producing a sound prototype after which no further changes were made and rolling-up production changes every six months.

1.9 Summary of Conclusions

This part presents the main findings of the research which were used to produce the implications, recommendations, conclusions and issues for further investigation (chapter 8). It also puts forward a way of conceptualizing the design - production interface which emerged during the process of the research project. This was that solutions to the problem of bridging the design - production interface can be grouped into three domains: methodology, technology and organisation. The findings of the research for methodology, and the work of others, demonstrated the following. 1) That there is a lack of available methodologies to help firms achieve design - production integration. 2) That the use of methodologies by firms is virtually insignificant (the use of design for assembly was reported as being 40% in the survey, but the structured interviews showed this was simply using CAD to manually check for design for assembly). It can be concluded that research effort into design methodologies or exhortation to companies to use such methodologies cannot redress the competitive imbalance that the UK is currently suffering.

Technology, specifically, the use of CAD and particularly CAD/CAM and CAD/CAM-FMS, showed more promise. However, it was found that technology also suffered from limitations. First, that CAD is overwhelmingly used as a drafting tool - its sophisticated use (Design For Assembly, Finite element analysis) is very limited. Second, only a very few firms have achieved a high degree of integration through the use of CAD/CAM-FMS. Third, even these have not achieved this integration for all of their product design, but usually for groups of similar components - aluminium manifolds and certain other machining operations. Thus, the potential of technology has yet to be realised by firms, and even the best practitioners have a long way to go before achieving total integration between design and production. Fourth, and most importantly in the present recession, firms do not have the money to invest in CAD and thus its applicability is even more restricted. Hence, it can be concluded that technology, while providing an important bridge between design and production and helping firms gain competitive edge, nationally is limited. This leaves the third option of organisation, or the management of the design - production interface.

It was seen particularly in the structured interview analysis that management of the design production interface was the key to explaining a firm's better performance. Even firms using similar technologies to produce the same product were more different in their management approach and attitude to managing product design. It was this difference in management that produced resounding results for the better firms, the others being merely complacent. An issue arose as to how to change management's attitude and it was seen in the one structured interview that the use of TQM had been a catalyst changing the way the whole firm dealt with the organisation of product design. TQM of course only peripherally addresses itself to product design, simultaneous engineering does this directly. Thus the direct and catalytic effect of simultaneous engineering is recommended as the way to restore Britain's competitive position. To this end more research is needed on simultaneous engineering - what it consists of, how to implement it, how to manage it and how to adapt it to particular companies. The author has already carried out research, as part of this project, on some of these issues (Riedel & Pawar 1991, Pawar & Riedel, 1993) and intends to develop the area further.

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CHAPTER 2

THEORY

This chapter presents the theoretical ideas that were drawn upon to formulate the theoretical framework of the research. The chapter is divided into two parts, first, the derivation of the theoretical framework (from a literature review of product design) and second the application of the framework to the design - production interface to elaborate the research questions. The first part considered what design is and the definition employed by the research; it included a review of the approaches to studying product design; a review of the relevance of manufacture to design; it put forward the concept of the design - production interface and developed it into the theoretical framework of the thesis; it reviewed models of the design process and justified the choice of the adopted model and discussed the measurement of design effectiveness. The second part is broken down into sections based on the four themes of the framework: the product specification, organisation and co-ordination, production considerations and CAD. Each section presents a literature review of the theme, and the derivation of the research questions.

2.1 Summary of Chapter

The theory chapter first of all examined what design is. Although, design extends across the whole company from environment (building) through communications (corporate image) to industrial design, for the purposes of the research it was taken to be product design. This was followed by a review of approaches to studying design. As an approach to studying design the study adopted a management one rather than a single discipline approach of marketing, design or production. This enables design to be studied from the point of view of the design and production functions instead of just one of them. The review of other studies of product design showed the following: a lack of generality, the studies being focussed on narrow products or industries, small sample sizes, self-selecting samples and non-random samples, geographically limited and an absence of the consideration of manufacturing considerations. The drawbacks of these studies informed the motivation and formulation of this study.

The importance of manufacturing to the effective introduction of new products was demonstrated. Manufacturing factors which were found crucial to product design were: that batch production is an obstacle to the introduction of integrative technologies, and that assembly and machining are the major production activities of mechanical engineering firms.

The conception of the design - production interface of being divided into two parts - the product specification and the design process - was put forward. A review of the models of the design process in the literature was carried out in order to select an appropriate one for use in the study. A simple linear model was chosen because it was simple and the use of a questionnaire prohibited examination of other complex models such as feedback or parallel.

The indicators used for the measurement of effective product design were the amount of modification carried out to a design after release of drawings to manufacture and the percentage of standard components included in a design. These two indicators allow both the measurement of the influence of manufacturing upon product design and vice versa, and also the measurement of the effectiveness of the product design itself.

An issue was how the firms responding to the questionnaire would be characterised. The characteristics chosen were the number of employees at the site, turnover of the company, age of production equipment, type of process technology (one-off, batch, or line), and finally the products manufactured. Characteristics such as the ownership of the firm (foreign or UK owned) were not judged important enough for inclusion in the study, as the primary focus is on design.

The first requirement of the research on product design was to determine the importance of design in mechanical engineering. Thus, the extent of design actually being carried out by industry (rather than firms simply being subcontract manufacturers) was important, along with the type of design (engineering or aesthetic). Further, the number and frequency of new product introductions was significant. The second part of the chapter then presented each of the four themes. The first section, the product specification section reviews the issues applicable to a manufacturing influence on the specification. This influence was broken down into the existence and format of product specification (written or verbal), the content and the personnel involved in drawing it up.

Second, the key issues for organisation and coordination were organisation structure: simultaneous engineering, integrated product-process design department or matrix organisation; coordination mechanisms: project team, product manager/ champion, meetings, ad hoc visits/ consultation and liaison officers; the personnel involved in coordination between design and production, the use of design reviews, vetoes and procedures plus production engineering input; the use of various standards and the factors which hindered and improved coordination.

Third, the review of manufacturing considerations narrowed them down to those which met the balance between importance to the research and questionnaire complexity and length. They were finally decided upon after taking into account the results of the pilot survey. The manufacturing considerations included in the survey were product cost, development costs, functional requirements, engineering design, styling, standardisation, production processes, plant, machinery, assembly techniques, labour requirements, materials, existing products, production control and product quality. The degree of involvement of production engineering personnel during the different stages of the design process was also important.

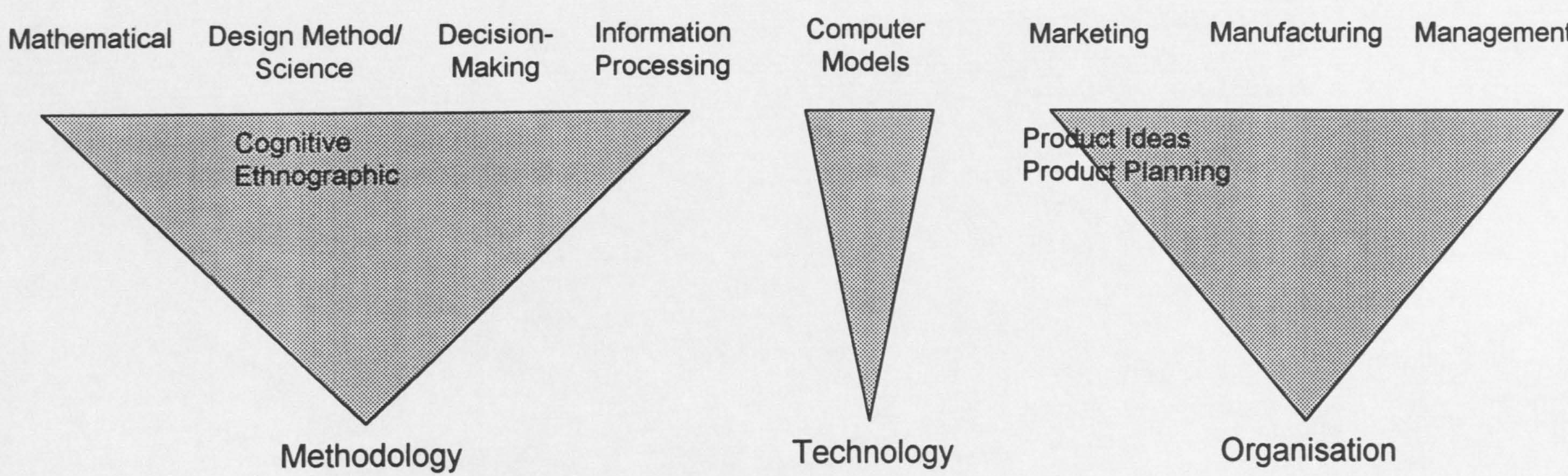
Fourth, the CAD section was a slightly more longer and fuller investigation of the use of CAD for product design in industry. This fuller examination was justified by the importance of CAD and CAM. The section was divided into two parts. The first part presented the distribution of CAD across the country as a whole and across industries, plus the uses of CAD and degrees of use in industry. These form an important backdrop to the use of CAD in mechanical engineering. The figures used were derived from the surveys of microelectronics use in industry carried out by the Policy Studies Institute over the period 1983-1987. CAD was most heavily used in vehicles (58%), electrical (52%) and mechanical engineering (41%). There were no significant regional effects. The number of workstations increased over the period but was due to the number of user firms increasing. Only 17% of all UK manufacturing firms used CAD for design. Firms bigger than 500 employees were more likely to use CAD workstations. The PSI survey did not provide any information about firms' usage of CAD, this research was thus designed to cover this aspect. The second part of the section detailed the issues for examination on the questionnaire. These issues were, what the CAD system was used for (type of drawing: 2D or 3D), advanced use of CAD (conceptual design, finite element analysis etc), the design stage when CAD was used, production engineering access to CAD and finally the achieved benefits. A major hypothesis as regards CAD was that it is mainly used for drawing and should more appropriately be referred to as Computer-aided <u>drafting</u>.

2.2 What is Design

Before proceeding it is worthwhile to clarify what is meant by design. Design within an organisation extends from environmental design (buildings, interior), communications design (corporate identity, graphics, packaging and product literature) to product design (industrial and engineering design, ergonomics). Outside an organisation there is architecture and fashion design. (Lorenz 1986, Olins ND, Hart et.al 1989, Walsh et.al 1988). Design also includes organizational design. Design properly applies to this whole range of design activities. The design of new products is but one element of design as a whole (Hart et.al, 1989). The term **design** in this thesis is restricted to design as **product design**. This is a slightly wider concept than just engineering design, a definition of which is given by Rooney & Steadman: "the definition of a mechanical structure, machine or system to perform a pre-specified function" (1987). The engineering design process can be said to concentrate solely on the tasks of the design of the functions of the product - it does not cover the specification of the product or its manufacture. It is the influence of production upon product design which is the focus of this study and therefore a reasonably wide conception of design is required which covers the areas upon which production is likely to impact. Importantly, however, the marketing aspects of product design, such as product planning, customer requirements etc, are excluded from consideration as they are more than adequately covered in the literature (recently Allen 1993). Hence, the thesis is concerned with product design, particularly new product design, the process of product design, its management and the impact and influence of production upon design.

There are various approaches in the literature to studying design, see those catalogued in Bessant (1979). Design can be viewed as an information processing activity. Information is collected (customer requirements, component specifications and material characteristics etc), evaluated and used to produce further information (product specifications, drawings, production schedules etc). Design can be seen as a decision making process, deciding on product function and performance requirements, materials, aesthetics and production processes. The communication behaviour and leadership style of design can be analysed. A problem solving approach can be taken. The cognitive and psychological aspects of design, that is, of the design process used by the individual designer can be studied and used to produce recommendations (Lawson, 1990). There is also the study and recommendation of design methods or science (Jones, 1970). Finger & Dixon (1989-I) point out that in Britain these studies have concentrated on being prescriptive - laying down what the design process should be (either chaotic

Figure 2-1 Approaches to Studying Design



and creative, or organized and disciplined, or that no process model should be imposed on a designer). Whereas in the United States studies have focussed on what the design process is, without discussing what it should be. The ethnographic approach falls into the latter camp and is useful in telling us what designers actually do and in moving towards an understanding of how they do it. Computer models of design attempt to assist or actually design things (Swift, 1987). However, the method of these approaches, ethnographic and computer are limited in that they focus on the designer and his (*sic*) activity of design. Although, some CAD/CAM computer design systems can actually produce complete components (see the CAD Structured interviews in this study) and other computer systems attempt to estimate the final cost of a product before it is produced (Currie et al, 1990). While the ethnographic approach recognises that design occurs across an organisation it has not been related to production (Bucciarelli, 1988). These latter approaches thus focus on a narrow aspect of design and do not cover its full spectrum. They concentrate on the individual designer and are inadequate bases for studying product design. This is because design is an organized activity carried out by more than one person and involving the interaction of many people - both inside and outside the company. The decision making approach is also limited in focussing on only one aspect of design - its decisions, it ignores the behavioural and management aspects. It also fails to recognise that constraints are placed upon design decisions by the way in which it is organized, especially the separation of design and production functions within companies. Information processing recognises this organizational basis of design, studies have been conducted of the flow of design information within companies. What information processing fails to address is the management of the design process, this is a larger issue than simply considering how the design information can be managed. Thus, in order to study the design - production interface an approach to studying design which includes the organizational, the behavioural, the managerial, and the technological bases of design, and which can allow for the informational and decision making aspects to be brought in, needs to be adopted. An approach which derives from a management perspective is thus best and was thus adopted. This was not to negate the other (limited) approaches, but to enable them to be brought in as and when needed - to encompass them.

These various approaches to studying design can be grouped into three categories (Figure 2-1): the methodologies and methods, including the cognitive and psychological approaches, into a *Methodology* group, the computer approaches into a *Technology* group, and the management approaches into an *Organisation* group. This topology of approaches is more fully discussed in the Conclusion. First, the studies which fall under the organisation or management approach to studying product design will be reviewed. The technology, that is CAD/CAM, will be discussed later below.

2.3 Other Studies of Product Design

A review of the existing studies of product design was conducted. The first issue of significance to emerge from the literature is the lack of attention paid to the type of firm in the studies concerned. Very few studies control for size of firm as measured by employment. Hence, no information is available as to the distribution of design departments between firms - do larger firms, as may be anticipated, have formally constituted design departments? The converse being the case with smaller firms? Simply stated, it is not known. Generally, studies have focused on products: motor cars (Roy in Walsh et al, 1992); or industries (narrowly defined), eg. the bicycle industry - cycles and components (Roy, 1984), plastic products - 49 firms (Roy in Walsh et al, 1992), industry categories: fast moving consumer goods (50 firms), fast-moving industrial goods (ie. industrial operating supplies) (91 firms), consumer durables (76 firms), components and OEMs (78 firms) and capital equipment (73 firms) (Service et al, 1988); Scottish engineering (widely defined) (42 firms) and textiles (19 firms) (Black & Baker, 1987); Scottish textiles firms (6) and engineering (14 firms) (Hart et al, 1989). Other studies of design using the survey method - in an attempt to be general rather than specific about design - have also been limited. The study by Ughanwa & Baker (1989) is limited because the studied sample was drawn from winners of the Queen's Award for Export. Such a sample can be said to be self-selecting and thus unrepresentative of an industry as a whole because it includes only the better firms. Also Ughanwa's sample was not controlled for industry or product and thus specific conclusions about particular industries or products are hard to derive. Roy & Potter (1990) focused on small and medium sized "manufacturing" firms (across all 13 manufacturing SICs) who were supported by the department of trade and industry's Funded Consultancy Scheme/Support For Design initiatives. This is a wide net, covering many different types of industries and products, but again is self-selecting and not representative of an industry(ies) as a whole. One study (Black & Shaw 1991) focused on engineering companies using the same make of CAD system. This is limited to CAD users and thus unrepresentative and also has a small sample size of 24. Ingersoll Engineers (1989) sent a survey to medium and large sized manufacturing companies (defined as over £20m turnover). The responses (264 firms, 32 mechanical) were slanted towards engineering but included metal goods, chemicals, non-metallic, energy, other transport, automotive, electrical, and office equipment. The study by Hollins (Hollins & Pugh, 1990) is limited to all manufacturers of "selected products" - no numbers or actual products are given for the sample. (A comparison of studies is given in Table 3-1 in the next chapter). The work of the engineering design centres (EDC) has also been limited. Newcastle has concentrated on marine and other made-to-order products. Lancaster on mechatronics. Strathclyde has concentrated on defence industries and on ceramic turbine blades. No attempt has been made by previous research to focus upon an industry category, such as mechanical engineering. Only one research study covers the UK mechanical engineering industry - the PSI survey of microelectronics use (which only looks at CAD distribution). Thus, the research undertaken by the project will, for the first time, focus upon an industry category, that of the UK mechanical engineering industry. The research will produce data which will characterise the UK mechanical engineering industry in terms of design: how many firms engage in design of their own products and their level of design activity as measured by new product introductions.

The narrowness of previous studies is exacerbated by their failure to consider the type of process technology in use by the firms. This is a crucial issue for the design of new products. Batch manufacturers - characterised by short production runs, changing products and, importantly, relatively fixed production technology (equipment) - are a case in point. It is vital that the design of new products takes these aspects into account, particularly the inflexibility of the production equipment (see section 2.4 below). More generally, studies of the design process have also tended to overlook the impact that production considerations and constraints have upon product design (Pawar, 1985). The present research set out to redress this imbalance.

2.3.1 Summary

It can be concluded that previous studies of product design have a number of limitations. Principally that they do not examine product design practice in general and there is a lack of consideration of production. Many studies have been case study based, using small sample sizes and companies which are not matched. Even the surveys have had small sample sizes with the samples selected on a judgmental basis rather than a representative one. This is compounded by the peculiar industries chosen for study, eg. bicycles and textiles, which are not representative of manufacturing industry. Further, their explanatory power is compromised by the diversity of products and industries contained within the one study. This makes the applicability of their recommendations questionable. The present study was designed to move on from these studies and to improve upon their methodologies. In particular it sought to address the issues which the other studies omit - generality and consideration of production. It is thus the best study of the design - production interface in the UK mechanical engineering industry completed to date.

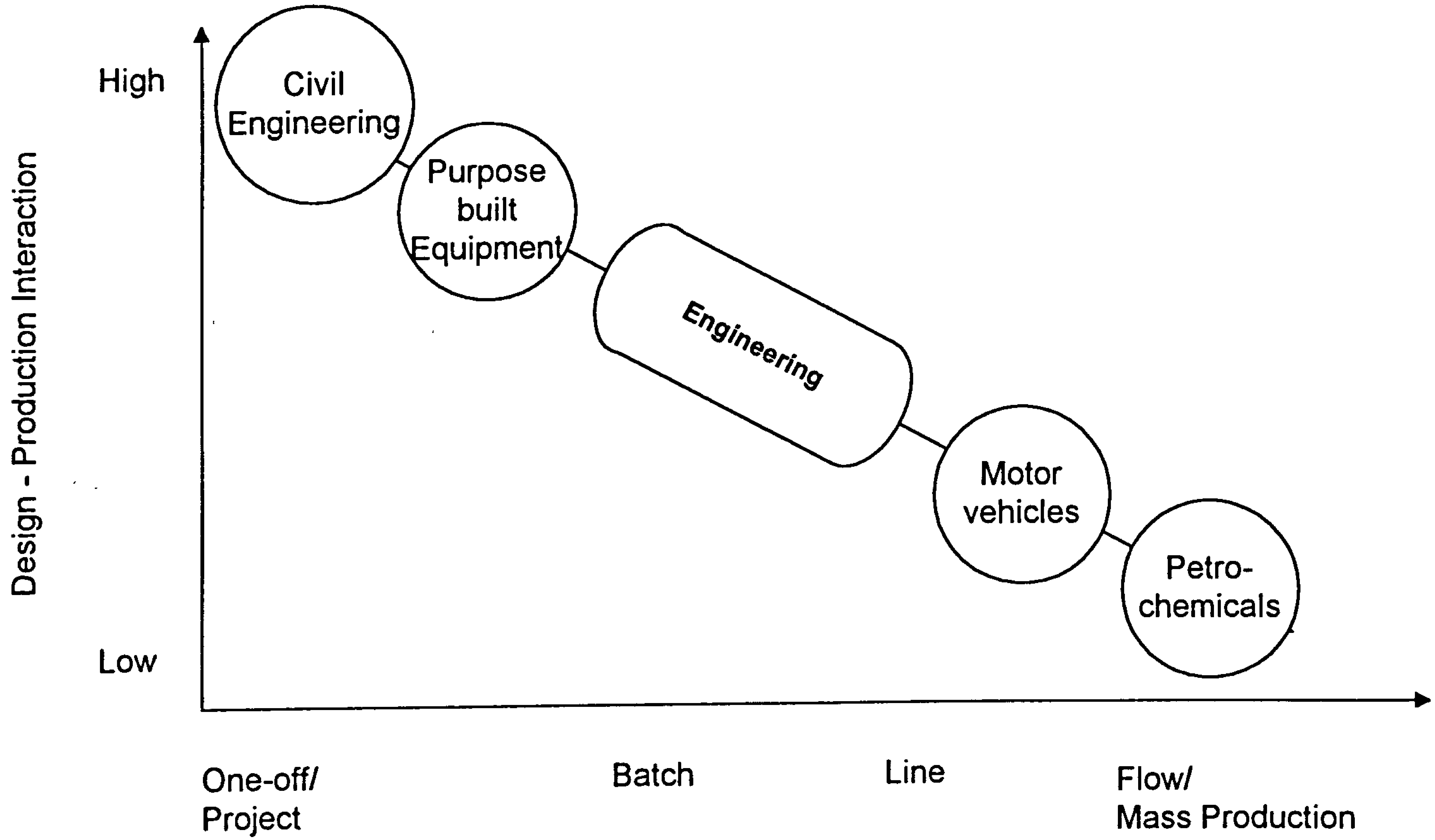
2.4 Manufacture

The other important aspect of the research is manufacture. The introduction of new products involves the co-ordination of the design and production departments. Information about the product needs to be passed to production in order that it can be manufactured. Information regarding the manufacturability of the product needs to be passed back from production to design. The interaction between design and process technology has been discussed by Hill (1985). As the type of process technology in use changes from one-off project to continuous process the amount of interaction between design and production decreases, see Figure 2-2. In the project situation design is all important because only one unit is to be made. Thus, as design and manufacture move hand-in-hand during the project, interaction is great. However, as only one unit is to be made manufacturability considerations are very much of less importance than those of design. If more than one unit were to be produced manufacturing considerations would become more important and the design would have to be modified to ensure that the product could be efficiently manufactured. The logical extension of this is continuous process production, where there could be no information transacted between design and production after the plant was commissioned. In this situation manufacture is all important. Similarly with mass/line production, eg. car manufacture, the design production interaction is of low intensity and a sequential one. The design is completed and then transferred to production all in one go.

With Batch manufacture, which is situated roughly half way between project and continuous process production the design production interaction is highly intensive and reciprocal (Winch, 1988). That is, a large amount of interaction between design and production is necessary, with neither being more important than the other. This implies that the flow of information from production to design should be almost as great as that from design to production. This is important because batch manufacturers tend to have fixed production facilities. Heavy investment in 'automated' equipment cannot rapidly be recovered (Blackburn et.al 1985). Hence, information about the manufacturing facilities and their capability has to be passed from production to design. Hence, it was concluded that the manufacture of products in batches is the ideal situation in which to study the design process of new products.

The study by Swords-Isherwood & Senker (1980) found that in Britain mechanical engineering accounts for approximately a third of total engineering employment. Further, they reported that the majority of employment in mechanical engineering involves production in batches rather than mass production. Blackburn et.al (1985) point out that despite the wide variety of manufacturing processes carried out (forming, casting, welding, cutting, surface finishing, making tools, jig and dies, and assembly) it is metal cutting which is the major activity. Haeusler (1981) offers a somewhat different picture stating that in the mechanical and electrical engineering industries about 50% of the work force is employed in assembly, and that costs and production times are determined to a large extent by the assembly process. Swift (1987) also points out that impressive improvements in manufacturing productivity have been made through improving tool and die life and through computer control of machine tools. Whereas, automation of assembly has not had the same impact. The solution to this, according to Swift, is the inclusion of design into assembly automation. This ensures that designs are assembly oriented and that components can be handled automatically. Thus, improvements to the consideration given to machining and assembly in the design phase by batch manufacturers can lead to great improvements. Hence, the choice of mechanical engineering as the industry to study would reap numerous benefits, not just for mechanical engineering but also for other industries where batch production and / or machining and assembly are major operations, such as motor vehicles, aerospace etc.

Fig 2-2 Process Technology & Design - Production Interaction



2.5 The Design - Production Interface

Previous research on the design process has identified the interface between the design and production engineering functions as crucial to effective introduction of new products (Flurscheim 1977, Pawar 1985). The literature on product design is somewhat selective. It tends overwhelmingly to be concentrated on the marketing perspective of product design, to underplay the importance of the design process as a whole and to virtually ignore production. The extensive literature on marketing considers the strategic issues of the timing of new product introduction, pricing, market share and product life-cycles. Production concerns do not even enter into consideration in this literature (eg. Allen, 1993). The design studies literature does not consider production aspects (Jones 1970, Archer 1974) - there was little in the journal *Design Studies*. Conversely, production engineering/ management rarely mentions product design - nothing in ten years of *International Journal of Production Research* and *International Journal of Operations Management*. Design - production considerations appear to fall between two disciplines. The engineering design literature, which one would expect fully addressed the manufacture of products, does so only partially. For example, Matousek in his book "Engineering Design" has just over one page on manufacture (p63-4). Pahl & Beitz (1984) the leading authorities on engineering design do somewhat better, with 10% (of 450 pages). Hubka another guru has 5% (of 95 pages). A second drawback of this literature is the assumption that the attention paid to production is in the gift of the designer, see for example Lawson (1990). This in fact does not match the reality of the design process, one in which designers, production engineers, managers and others work together as part of a process towards the introduction of a new product. Part of the reason for the under-representation of design for manufacture issues is that it falls between the two stools of two different disciplines (design and production engineering/ manufacture). This, of course, reflects the separation of these two functions within industry. This review suggests that the consideration of production during design is under-researched, with very little work having been done on it. This study attempts to redress the balance. The study does not undermine the other studies as they had their own focus. There is a need to add and complement the previous studies with ones having the design - production interface as the focus. Considerable work still needs to be done in this area, this study being one contribution to that work.

The mediating concept to achieve the linkage of the designer, design process and production is that of the design - production interface. The second element is the conceptualisation of the product design process into two separate phases - product specification and product design or development. This latter approach has been well formulated in the literature (Flurscheim 1977, Pawar 1985, Topalian 1980, Hollins & Pugh 1990). This conceptualization provides an effective split between the process of specifying the product and the process of designing the product. It allows for a concrete output (the product specification) to be produced before product design actually starts. Thus each of these two things can be studied independently and then compared - did the design match up to the specification? The product specification is dealt with below. The design process is covered in the next section. The transition from designing a product to producing it comes with the transfer of drawings from the design office to the production personnel - whether production engineers or shopfloor personnel. This transition is the second important interface between design and production. Once past this point changes to the design are expensive and time consuming.

The key to bridging the gap between design and production is to provide techniques to overcome it. This can be achieved, as was argued earlier, by either methodology (eg. the product specification), technology (eg. CAD) or organisation (eg. integrating the organisation). Four themes thus emerge for investigation by the research: the product specification, the organisation and co-ordination of the design process, the consideration of production, and CAD. Each of these is elaborated upon later, first it is necessary to examine the design process itself.

2.6 The Design Process

> "Is a 'Theory of Design' timely? Yes! It is overdue. Why? Because the moment you see something around you that you cannot explain, the time has come to construct a theory" (Hatvany in Yoshikawa & Warman, 1987, p134 - cited by Bernus Computer-aided Design 21 (9) November 1989.)

In order to carry out research on the interaction between design and production functions, the consideration of production and especially when production is considered a model of the design process is needed. This model allows the research to ask when aspects of a design are considered and not just which. The proposition would be that the earlier consideration of production would lead to better design performance. Thus the pattern of better companies' consideration of production could be compared to poor performing companies to see if particular practices were significant.

The design process is a nebulous entity which takes on many shapes, forms and definitions. As Cross & Black (1988) put it in defining the engineering design process "design is a subject that is riddled with various and differing terminologies and definitions, all of which are open to any degree of (mis)interpretation" p215. Loosely the design process is the process of introducing a new product. The questions are: when does, or should this process begin, when does it end, what stages, if any, is it composed of, and what activities does it include. Some models of the design process include the marketing end of new product introduction, for instance the search for new product ideas, market segmentation and product pricing, while others consider only the engineering design and omit manufacture altogether. Some models while assuming a linear progression from concept, design to manufacture allow for loops back to earlier stages to improve the design. Other models allow for multiple iterations through the whole model or through parts of it. Some models are broken down into stages each of which has to be passed through in sequence whereas others imply a single unbroken continuous process. The following types of model can be identified: linear, feedback, iterative, sequential, parallel, integrated, rugby and spiral, shown in Figures 2-3 to 2-10 respectively.

The design process is also a recursive concept in that design engineers may tell you the process they engage in when designing a new product but they were already taught what the design process was when they were educated. Thus, the concept of the design process goes around in a circle from educators to practitioners to researchers back to educators and then onto the next generation of practitioners. Hence, to investigate the design process - to come to know what it is - one has to break into this circle at some point. This has to be done with the recognition that elements of the circle previous to the breakpoint have influenced the model of the design process derived at this point. Therefore, asking a design engineer to outline their idea of the design process would result in a textbook account learnt in student days modified by experience in the firm(s) the designer had worked in. There would then not be "one" model of the design process but a fluid and changing one adapted to circumstance. This is a problem for research investigating the design process in industry because the context (of the firm and the designer) should ideally be included in the model derived. This, of course, requires an in-depth and time-consuming study. In order to get round this problem, and still throw some light on the design process and the consideration of production within it, a simplified model of the design process was adopted from a review of those present in the literature.

Fig 2-3 A Linear Model of the Design Process

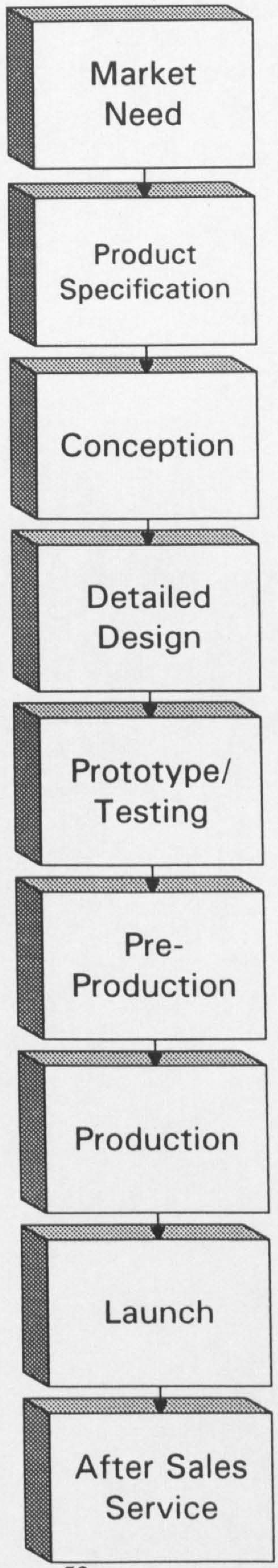


Fig 2-4 Feedback Model of the Design Process

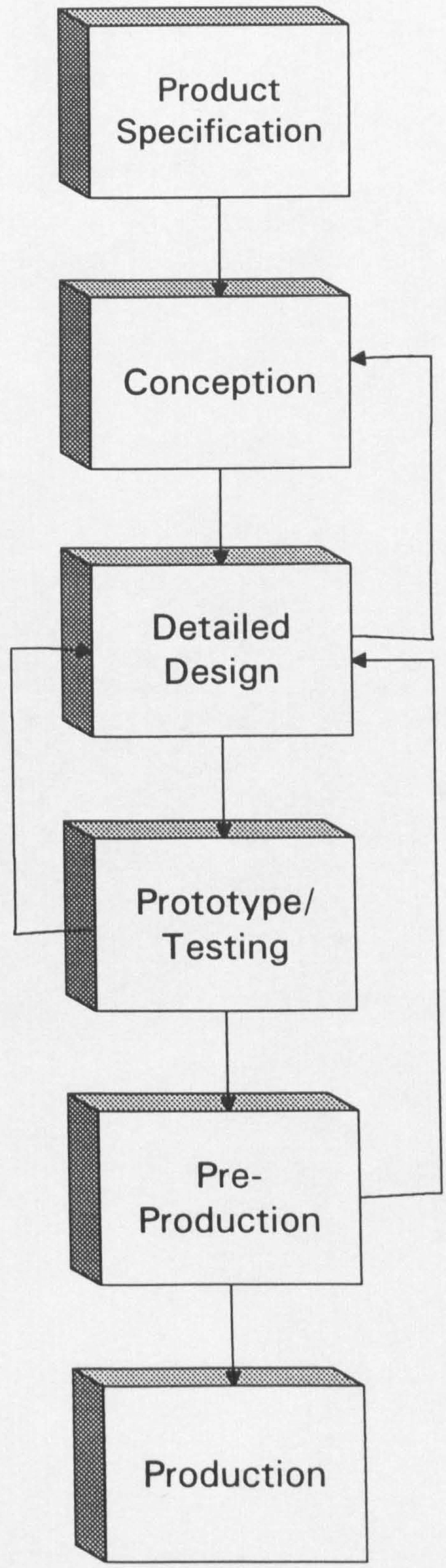


Fig 2-5 Iterative Model of the Design Process

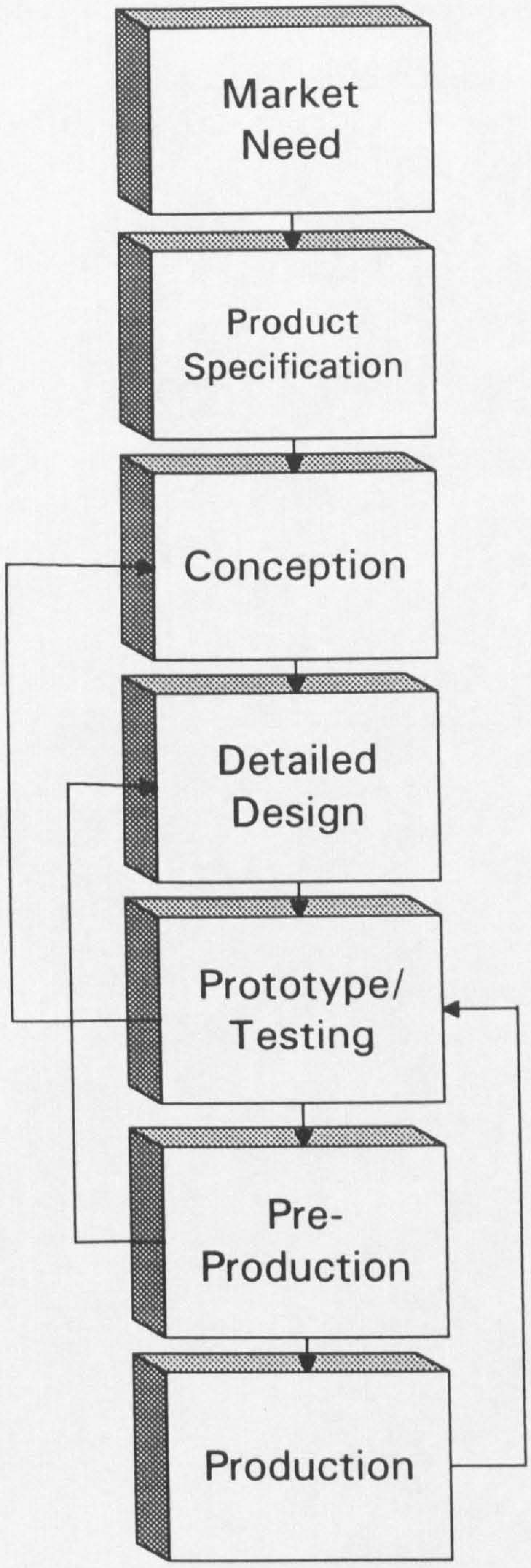


Fig 2-6 Sequential Model of the Design Process

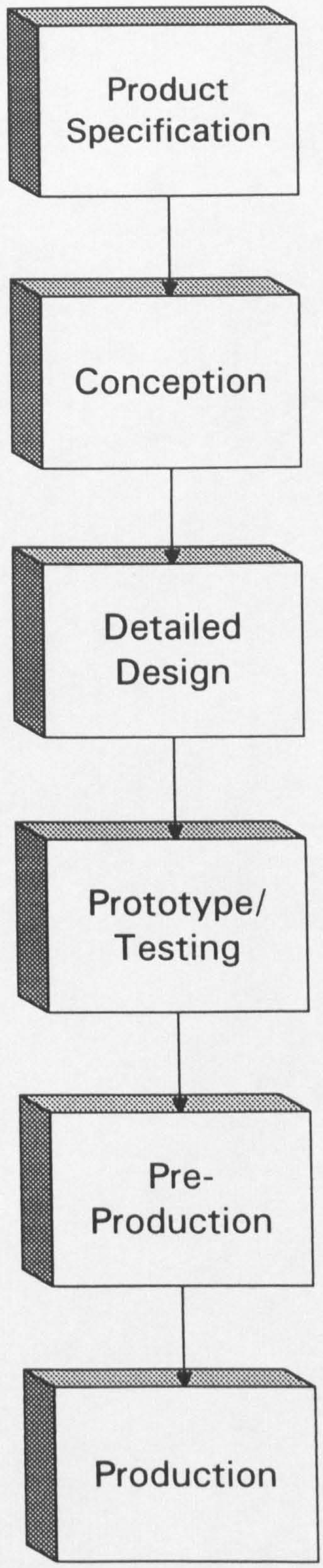


Fig 2-7 Parallel Model of the Design Process

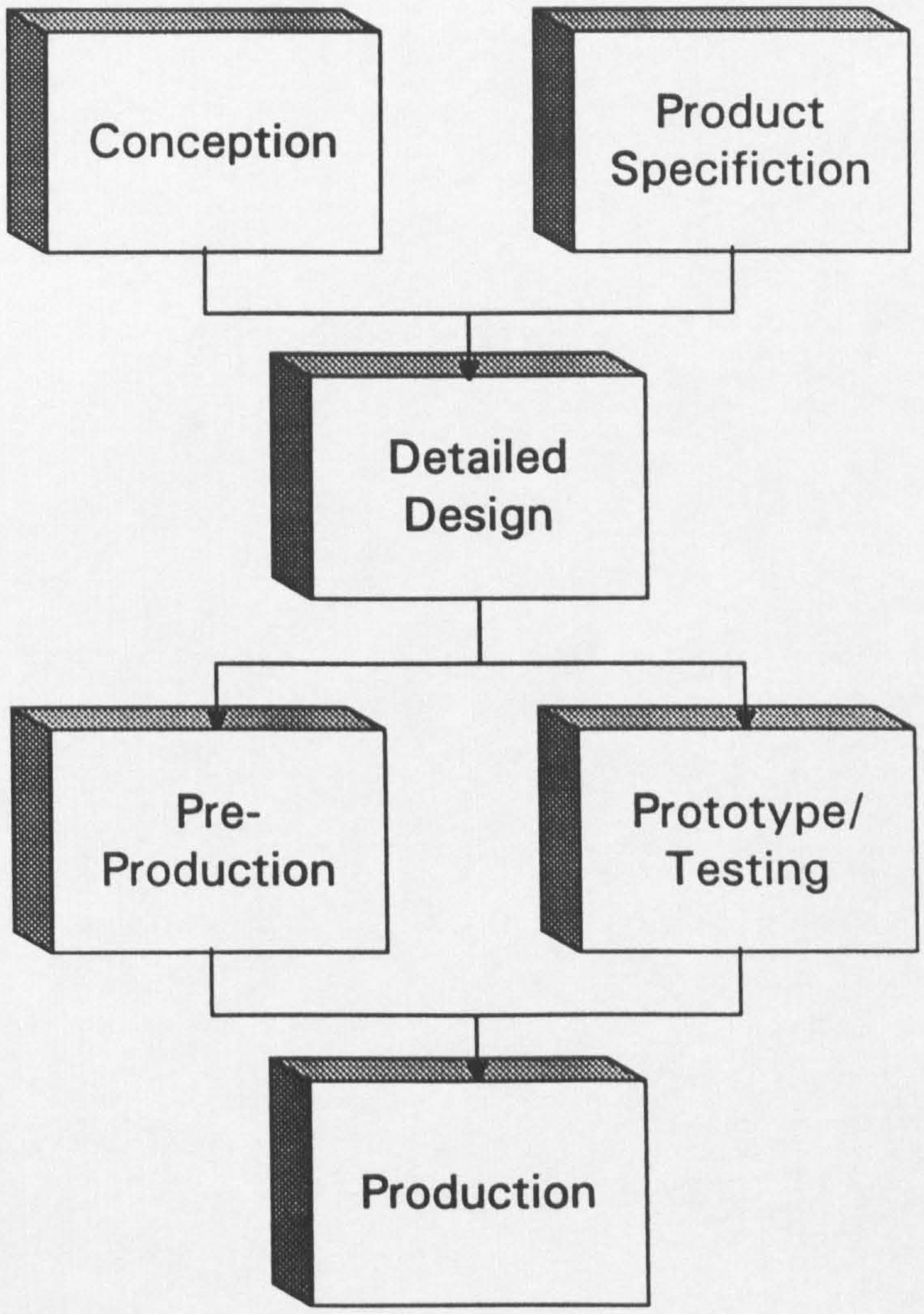
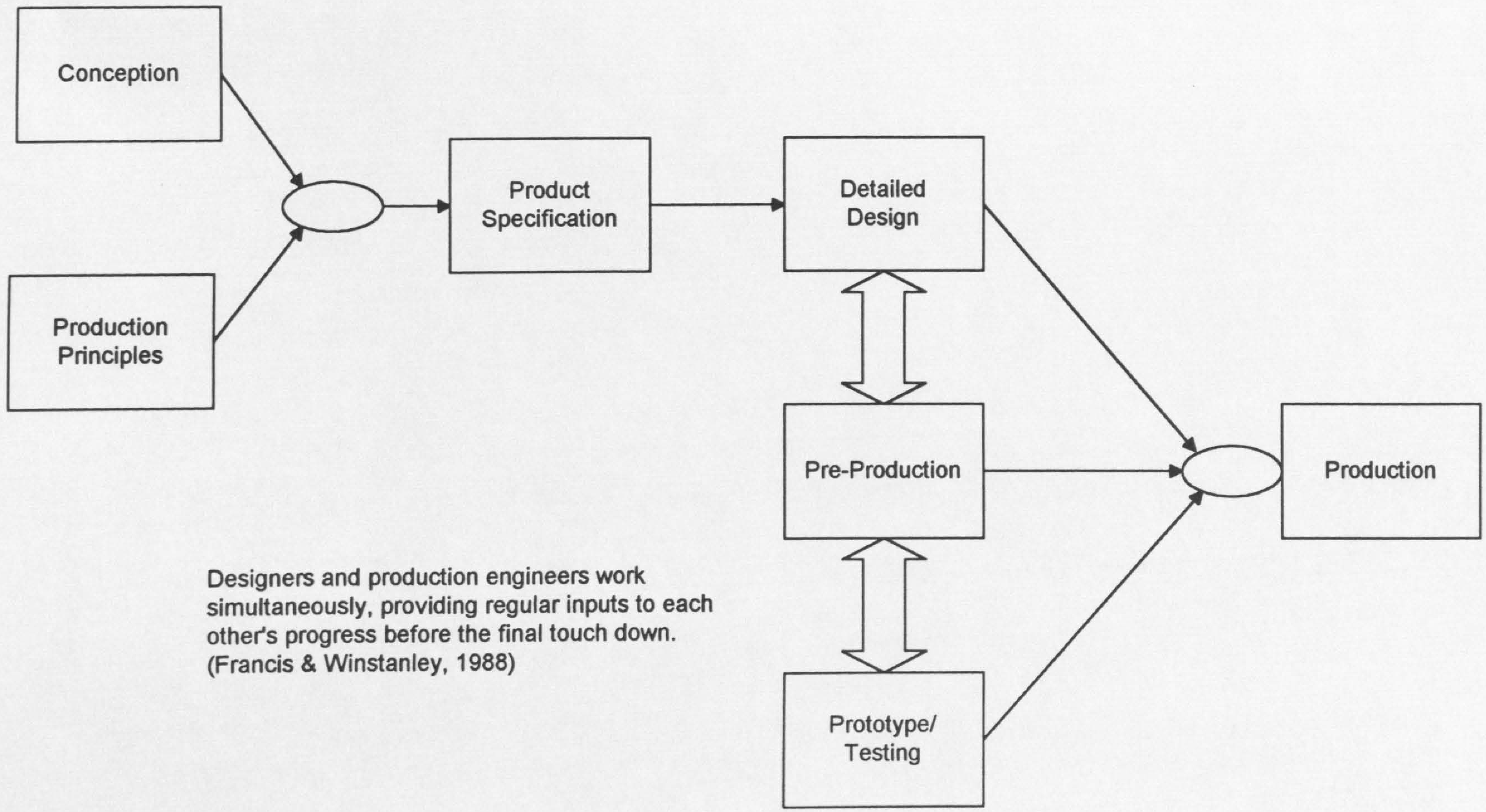


Figure 2-8 Integrated Model of the Design Process

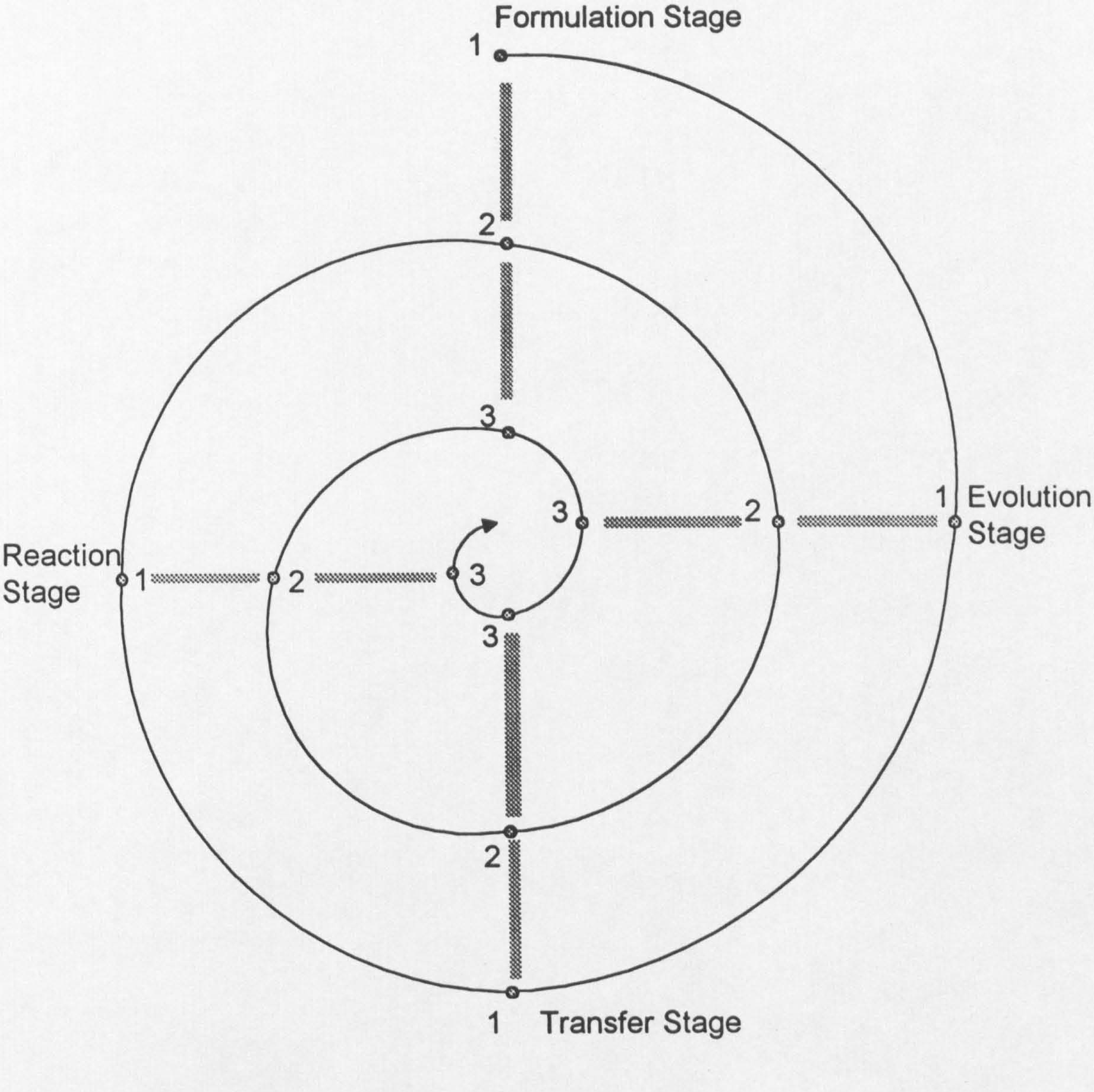
Adapted from Hein et. al. 1984

Figure 2-9 Rugby Model of the Design Process



Designers and production engineers work simultaneously, providing regular inputs to each other's progress before the final touch down. (Francis & Winstanley, 1988)

Fig 2-10 A Spiral Model of the Design Process



Adapted from Bennett et.al, 1988

Models of the design process can be grouped into three: engineering models, cognitive models and computational models (Vora & Helander, 1992). Engineering models are prescriptive models that view the design process as an ordered progression from formulation of the esign problem to selection of the solution. Cognitive models attempt to model the designer's behaviour and thought processes in a way which accounts for the dynamic nature of the design process. Computational models are a recent innovation which attempt to use computers to produce design aids for designers. Cognitive models of the design process, while being useful in themselves, are inappropriate in the present study because they suffer from three important limitations. They focus only on designers, they omit the rest of the design process (eg. product specification and pay only lip service to manufacture), they do not consider the actual practice of design in its context of being carried out in organizations. Also computational models fail to consider the whole design process and typically concentrate on well defined domains such as design for assembly. Thus engineering models are the most relevant to the present study.

The model of the design process adopted by the research was derived from a literature review of the design process. Many models of the design process put forward were consulted and their relevance to the present study examined. A linear model of the design process was chosen. The reasons for this were firstly its simplicity and ease of understanding and second the constraints imposed by the questionnaire research method. The primary limitation of a questionnaire is that it is difficult to record complicated processes on it. For example, attempting to ask about feedback, and especially when it occurred and what was fed back is an almost impossible task. It would surely lead to a lengthy questionnaire, which would be unlikely to be filled in - and be difficult to analyse. Thus complicated, iterative or feedback, models of the design process should more properly be investigated with case study methods. This leaves linear models as the most suitable for investigation. The issue then becomes which linear model of the design process to adopt; its length, number of stages, what stages to include and the content of the stages.

The characteristics of the reviewed models of the design process are shown in Table 2-1. The length of the design process in these models varies from 4 to 11 stages. Although the number of stages is not significant only their content. A summary model of the whole design process was given in Figure 2-3. It can be seen that nearly all models start with need or market recognition, conception, feasibility or criteria formulation.

Table 2-1 Characteristics of Design Process Models

Author	Date	Number of Stages	Begin Stage	End Stage	Considers Manufacture
Shahin	1988	10	Recognition of need	Development for Improvement	yes
Black & Baker	1987	5	Opportunity identification	Introduction	no
Archer	1974	11	Strategic planning	Production	yes
Hawkes & Abinett	1984	4	Initiation	Production	yes
Roy	1984	6	Basic Research & invention	After sales service	yes
Bradbury	1989	4	Feasibility	Exploitation	no
Wild	1989	4	Marketing need	Production	yes
Oakland	1989	5	Conception	Pre-operational	no
Rooney & Steadman	1987	4	Specification	Manufacture & Sale	no
Stark	1988	6	Concept	Preparation for Manufacture	yes
Hein et.al.	1984	5	Need Research	Realisation	yes
Bennett et.al.	1988	4	Formulation	Reaction	yes
Cross & Black	1988	5	Task Clarification	Manufacture	no
Pugh	1988	6	Market	Sell	yes
Meister	1989	4	Formulation	Selection	no
Ballay	1987	5	Criteria Formulation	Release Drawings	no
Hubka	1988	4	Elaboration	Detailing	no

Table 2-2 Models of the Design Process

Author	Date	Begin Stage	Subsequent Stages					
Shahin	1988	Recognition of need	Definiton of problem	Feasibility study	Creative Designs	Evaluation & Decision Making	Detailed Design	Building & Testing
Black & Baker	1987	Opportunity Identification	Design	Prototype Development	Prototype Evaluation	Introduction		
Archer	1974	Strategic planning	Research	Feasibility	Design	Prototype Development	Trading Study	Production Developement
Hawkes & Abinett	1984	Initiation	Conception	Feasibility	Design & Development	Pre-Production	Production	
Roy	1984	Basic Research & Invention	Concept Design	Prototype Development & Testing	Design Engineering	Tooling & Industrial Engineering	Test Marketing	Manufacturing & Marketing Start-Up
Bradbury	1989	Feasibility	Market Research	Prototype Design	Laboratory Process Design	Prototype Evaluation	Product/Process Development & Evaluation	Exploitation
Wild	1989	Marketing need	Product Specification	Outline Design	Detail Design	Final design	Product Development	Prototype Manufacture
Oakland	1989	Conception	Acceptance: valid Spec	Execution: Trials, pliot-plant	Translation: process design, development team	Pre-Operational: Produce Quanitity, validate		
Rooney & Steadman	1987	Specification	Generation of Alternatives	Evaluation: performance, cost, optimisation	Manufacture & Sales			
Stark	1988	Concept	Design Entry: Schematic	Validation & Simulation	Physical Design	Test Generation	Preparation for Manufacture	
Hein et.al.	1984	Need Research	Product Principle	Design	Preparation	Realisation	Product in Use	
Bennett et.al.	1988	Formulation	Problem investigation, product specification	Evolution: solution refinement, protoytpe, design freeze	Transfer: Manuf drawings, process modification, production, delivery	Reaction: customer appraisal, after sales service		
Cross & Black	1988	Task Clarification	Conceptual Design	Embodiment Design	Detail Design	Manufacture		
Pugh	1988	Market	Specification	Concept Design	Detail Design	Manufacture	Sell	
Meister	1989	Formulation	Generation of Alternatives	Evaluation	Selection of Preferred Alternative			
Ballay	1987	Criteria Formulation	Information Translation	Concept Generation	Detail Refinement	Release Package: drawings & documents		
Hubka	1988	Elaboration	Conceptual Design	Laying Out	Detailing & Elaboration			

Table 2-2 Models of the Design Process, continued

Author				End Stage	Considers Manufacture
Shahin	Designing for Production	Release of Product	Development for improvement	Development for improvement	yes
Black & Baker				Introduction	no
Archer	Manuafcture & Marketing Start-Up	Production Planning	Production & Sale	Production	yes
Hawkes & Abinett				Production	yes
Roy	Production, Marketing & Sales	Trouble-shooting		After sales service	yes
Bradbury				Exploitation	no
Wild	Manufacture			Manufacture	yes
Oakland				Pre-operational	no
Rooney & Steadman				Manufacture & Sale	no
Stark				Preparation for Manufacture	yes
Hein et.al.				Product in Use	yes
Bennett et.al.				Reaction	no
Cross & Black				Manufacture	no
Pugh				Sell	yes
Meister				Selection	no
Ballay				Release Package	no
Hubka				Detailing & Elaboration	no

The marketing aspect is outside the scope of the present study, thus it can be said that some form of conceptualisation or requirements formulation is the first design stage. Also looking at the end of the design process the sales and after sales stages are outside the scope of this study. Thus, for the adopted model production, that is, full production of the product (not just test production runs) was chosen as the last stage of the design process. This leaves the choice of the interim stages. Table 2-2 presents, in simplified form, the stages of the models derived from the literature. Significant stages can be identified as follows: detail design, prototype development/ evaluation, preparation for manufacture/ pre-production. The other significant issue is the consideration of manufacture. Just over half the models (9 as against 8) had some mention of manufacture or its consideration. The type of consideration, or detail, varied from stating that production should start in a particular stage (Roy 1984, for example) to listing production development, tooling, prototype manufacture and preparation for manufacture/ designing for production (Shahin, 1988). Second, this consideration with the exception of Hein et. al's integrated model (Figure 2-8) occurred late in the design process. There is thus the issue of what consideration of production includes, this was dealt with in section 2.12 below. The resulting model of the design process (shown in Figure 2-11) was: conception, product specification, detailed design, prototype / testing stage, pre-production and production.

These stages have the following characteristics (Figure 2-12). Conception: Here the basic concepts of the design are set down: what functions does it perform and how; Product Specification: This is a key transitional stage in which the specification of the product is set down on paper. This would include its performance, what type of technology it utilises and reliability etc; Detailed Design: During this stage the product is designed, drawings are produced, mock-ups made and evaluated, the final drawings of this stage are then handed over to production and production engineering; Prototype/ Testing: In this stage actual working prototypes are made and their functionality and performance tested. The results of this stage can be used to adjust and improve the design and to check out how the product will be manufactured; Pre-Production: This stage is where the product is geared up for production. Dies, jigs and fixtures are made for the production machines, CNC programming is done, the decision of which production processes and machines is made and the settings for these are determined; Production: full production of the product is undertaken (just previous to or after the product has been launched on the market). This completes the examination of the design process. Next a few preliminary issues, design performance, firm characteristics and design intensity, are discussed before moving into the four themes.

Fig 2-11 The Adopted Model of the Design Process

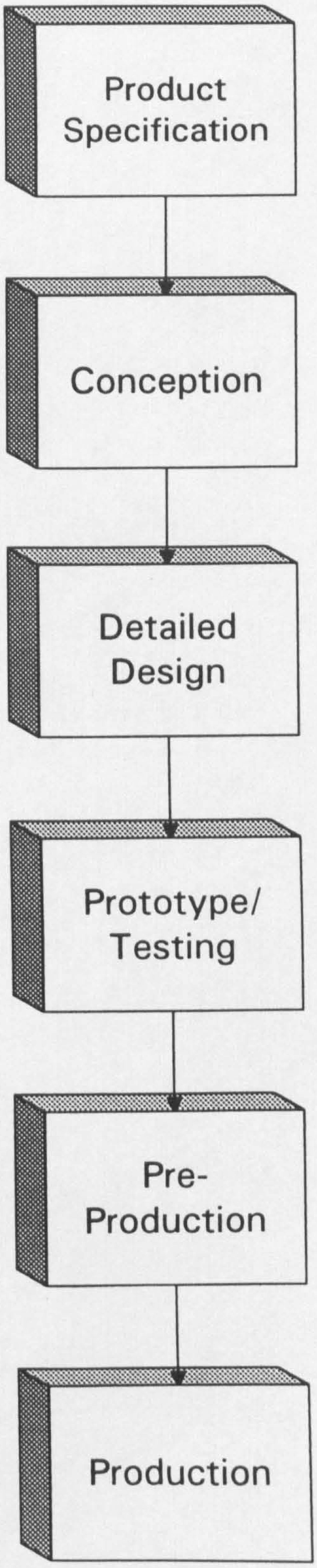
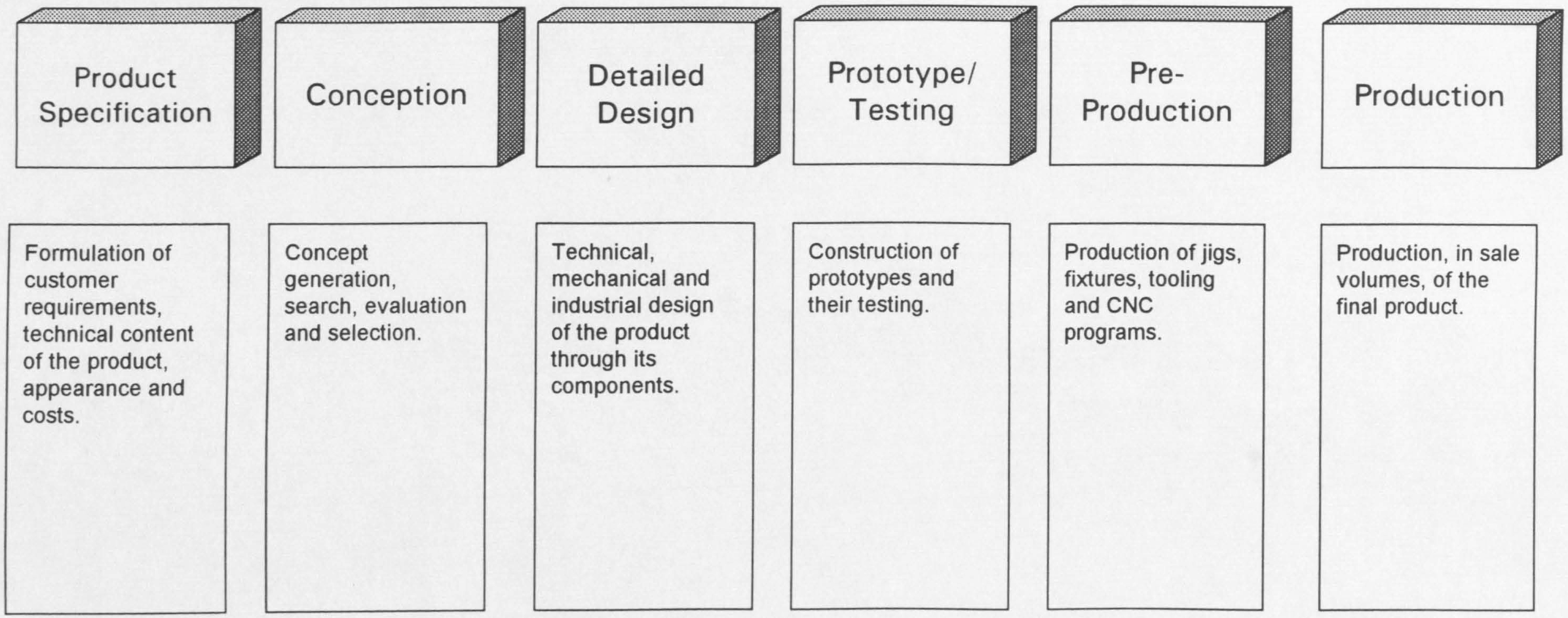


Fig 2-12 Characteristics of the Design Stages of the Adopted Model



2.7 Design Performance

In order to produce guidelines which can be used by companies to effectively introduce new products there needs to be a way of classifying, or measuring, the design performance of companies. Measuring the performance, particularly financial performance, of companies is a sensitive methodological issue (See Hart et al, 1989 and Oakey et al, 1988). Measuring profit growth is highly problematic. Abnormal profits can be produced by companies simply by selling off any property or assets they own. Thus, profit performance cannot be unequivocally attributed to good product design. Other measures of commercial success such as exports also present difficulties - again they may be due to abnormally large orders in any one year. It was intended to determine the financial performance of companies by following Black & Baker (1987) and use average sales growth over a four year period. This is a safer measure as it relates directly to the operations of a company. Unfortunately, time constraints on the project did not allow us to pursue this avenue of financial analysis.

The other studies of design have used measures of good design such as the winning of Queen's Awards (Ughanwa, 1989). Walsh et al (1988) used a number of indicators of a firm's reputation for producing well designed products: the total number of awards, prizes, etc (Design Council and industry awards) for designs won by the firm, the number of times the firm's products were cited in the Design Council's selection of well-designed British goods, and the number of times a firm was mentioned by its competitors as making the best designed products in their industry sector (Walsh et al 1988, p205). These measures are all subjective and are thus limited. For example, even the Design Council cannot be aware of every product manufactured in Britain, its judgement as to good design is thus limited. Likewise, companies do not carry out systematic and objective assessments of their competitors' designs. Further, the best designed product may not be the best seller. Which means that the customers' opinion counts more than competitors' or the Design Council, but this opinion was not included in Walsh et al's study. Instead, an objective measure of design performance is required which can be easily measured and used to compare the performance of all companies (something which award based measures cannot do). Two measures of design performance were used. These measure the performance of companies' implementation of designs into production. The first measured the number of component modifications carried out after drawing transfer to production (following Pawar, 1985). Second, as a complement to this the number of standard components in a design would also be measured. These two measures can be objectively measured. Other measures, such as, improvement to product quality cannot be so measured. Also because the focus of the study is on the design - production interface they directly measure the effectiveness of this relationship. Good designs should have low modification and high standardisation - indicating that the designers had designed the product for manufacture. In a wider context other measures of successful product design, such as those mentioned above or optimal utilisation of resources could be used. The two measures, modification and standardisation, provide the cross sections of design performance through the four themes of product design.

2.8 Firm Characteristics

The characteristics that were determined to be worthy of investigation were the number of new products that firms introduced each year, regional distribution, establishment size in terms of employees, number of company employees, sales turnover, the age of production equipment, the type of process technology (one-off, batch, or line), the type of product manufactured (intermediate, final or consumer) and finally the actual product manufactured. Characteristics such as the ownership of the firm (foreign or UK owned) were not judged important enough for inclusion in the study, as the focus is the impact of manufacturing upon design.

2.9 Design Intensity

First, the research sought to determine if the responding firms actually designed the products they manufactured. This inquiry would tell us the proportion of mechanical engineering firms that carried out sub-contract work which involved no design input by the firm itself. Secondly, given that firms design their own products how much design work do they do. This can be measured by the number of new products introduced per year or by how often new products were introduced. These two measures would provide an indication of the level of design intensity in the UK mechanical engineering industry. Second the research sought to measure the extent of design activities within firms. Thus, the types of design activity, engineering and aesthetic, carried out by the firms was investigated. And whether this was done in-house or subcontracted out. Also the use of design consultants was examined.

This concludes the first part of the theory chapter. The next part presents the theoretical framework of the thesis presented in terms of the four themes: product specification, organisation and co-ordination, consideration of production and CAD.

2.10 The Product Specification

This section presents the literature used to draw up the theory of the role of the product design specification in the design process. Product specifications are a key element of the product design process. The use of them greatly influences the effectiveness of new product introduction. (Hollins & Pugh, 1990; Pawar & Riedel, 1990). The specification lays down the parameters to which the design must conform. It thus takes in the following requirements of the product: functional, quality, aesthetic, material, cost etc. Rarely, however, are production considerations included in the specification. Most of the literature on the product specification, with the exception of Hollins & Pugh, does not enumerate in detail the content of the specification. Nor does it consider, or recommend, the personnel involved and their extent of involvement in the drawing up of the specification. The present research sets out to overcome these limitations to produce recommendations for the compiling of product specifications. In this it is first of all necessary to determine if firms compile product specifications and in what form: written, verbal or both. Second, the characteristics of firms that influenced which format of specification was used. Third, the content of the specification and, more particularly, the attention paid to production considerations came under scrutiny. Fourth, there is the question of the personnel involved in compiling the specification and their degree of involvement. A section of the questionnaire was designed to resolve these issues (Appendix B). Finally, there is the issue of the effectiveness of the product specification. This would be measured by the amount of modification and standardisation as discussed in the design performance section of this chapter.

2.10.1 Firm Characteristics

The research investigated the compilation of product specifications by companies and the characteristics of the firms using them. The characteristics that were determined to be worthy of investigation were the number of new products that firms introduced each year, regional distribution, establishment size, by sales turnover, by the age of production equipment and by type of process technology. An analysis was performed to see which of these characteristics affected the format of the product specification (written or verbal).

2.10.2 Content of the Product Specification

The content of the product specification of interest to the research was its reflection of production needs and concerns. In particular, was production being considered "up-front", that is at one of the very early stages of the product design process. Thus, questions were formulated to inquire into the consideration given to production aspects in the product specification. Design aspects were also included to compare the relative degree of consideration of design and production aspects. The aspects were derived from a literature review of product specification and production engineering literature (this derivation is explained in Section 2.12: The Consideration of Production). The aspects investigated were: functional requirements, engineering design, styling/ appearance, product cost, development costs, project duration, production processes, production machinery, assembly techniques, labour requirements, compatibility with existing products, use of standardisation and materials.

2.10.3 Personnel Involved in Product Specifications

The research investigated the personnel involved in drawing up the product specification and their extent of involvement. Again the involvement of production personnel and the inclusion of their expertise was important. Also a comparison with personnel who would be expected to contribute to the specification, such as marketing and designers, was set up. Further, the influence of customers and suppliers both of whom have impacts manufacturing was included. The list of personnel was (cf. Pawar & Riedel, 1990): finance, marketing, sales, designers, design management, production engineering, production management, R&D, general management, customers, suppliers and others (for specification by the respondent).

2.11 Organisation & Coordination

The research investigated the level of institutionalisation of design within firms, that is possession of design, R&D and development departments, and the factors influencing companies' possession of these. The form of organisation of the design and production functions: integrated product process departments, matrix organisation and simultaneous engineering - and the factors influencing their use were also examined. The co-ordination mechanisms (project teams, product managers, meetings, consultation and liaison) and the personnel involved were investigated. An analysis of which organisational forms and co-ordination mechanisms gave better design performance, as measured by design modifications and component standardisation, would be undertaken.

2.11.1 Organisation Structure

Institutionalisation was conceived of as possession of design, development and R&D departments but also their location, on-site or off-site. Possession of these departments off-site would imply that the company was part of a larger group and that the design and manufacturing functions were physically distant. Thus, co-ordination between the two would be hampered. It may also imply that it was not necessary for companies to design the products they manufacture, or at least it was not as important as hypothesised by this research. This issue would be resolved by the survey.

The next part of the research considered the two separate issues, of the organisation of, and the co-ordination between, design and production functions. A similar distinction was made by Winch (1988) for studying the implementation of CAD/CAM. Winch adapted the classic text on organisation design of Galbraith (1973). The structure of the organisation of the relationship between design and production can take many forms. The key ones, as far as the interaction with production, are: simultaneous engineering, integrated product-process design department and matrix organisation. Each of these in turn is a more formal and rigid organisational structure. Simultaneous engineering (illustrated in Figure 2-13) involves the tight co-operation of product and process design personnel, it does not necessarily take on anything more formal than a project team form (Riedel &

Pawar, 1991). An integrated product-process design department is one in which both product and process design personnel are located in the same formally constituted department. Matrix organisation is where the personnel from separate product and process design departments are assigned responsibility for individual products. The research set out to investigate the distribution of these three types of organisation of the design - production relationship. It is hypothesised that the larger the firm the more formal the organisation of the relationship. The survey aims to determine which of these organisational forms is more effective for new product introduction.

2.11.2 Co-ordination Mechanisms

Although a formal organisational structure may be in place for design and production there is still the issue of the management and co-ordination of design activities. Again, following Winch and Galbraith, the following mechanisms of co-ordinating design were identified: project team, product manager/ champion, meetings, ad hoc visits/ consultation and liaison officers. Project teams and meetings both involve more than one person, whereas the others involve individuals. Again the analysis of the influence of size will provide interesting results. Product managers can have considerable individual authority and responsibility, it will be interesting to see how much industry uses them.

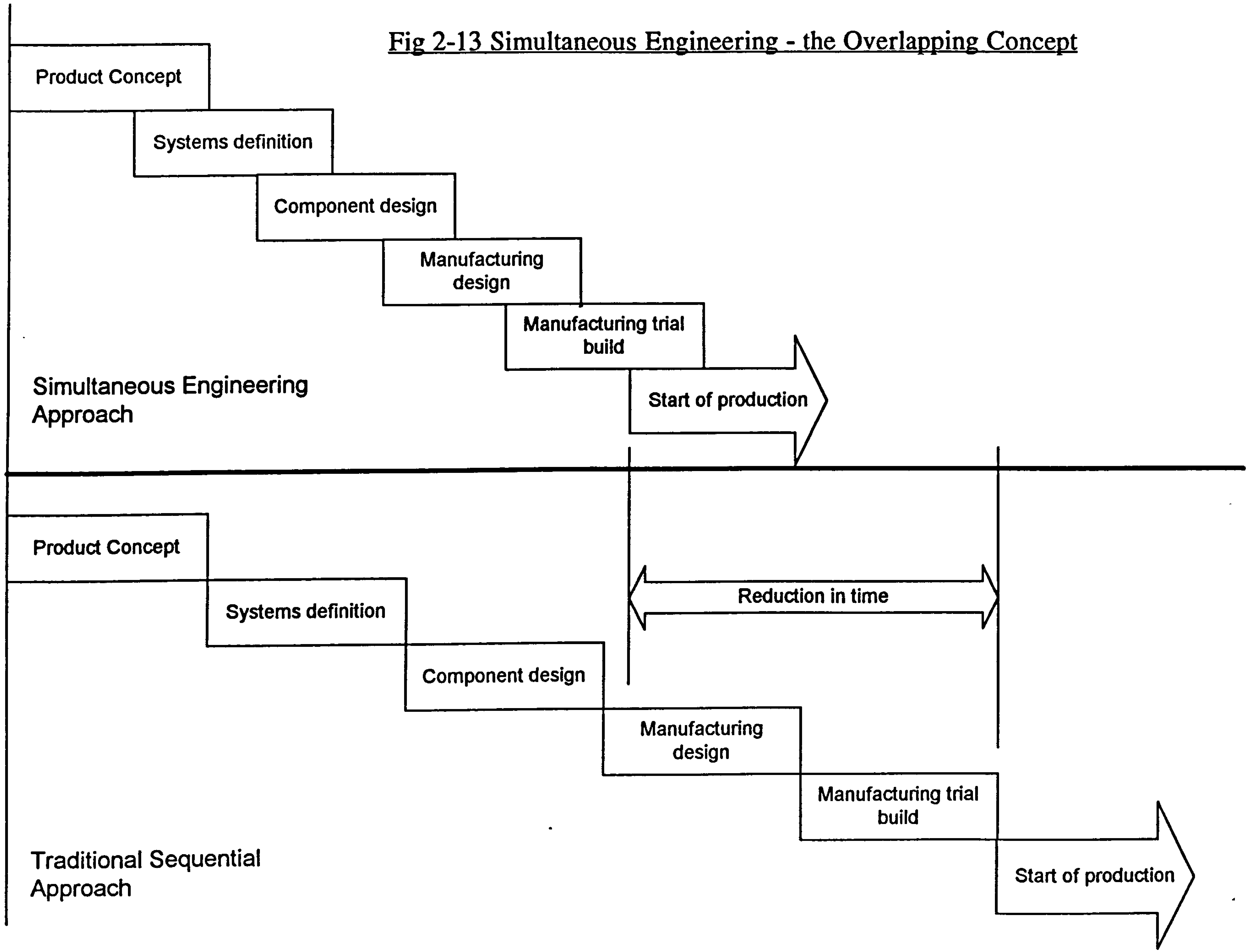
2.11.3 Co-ordination Personnel

The research also sought to determine which personnel are involved in these co-ordination mechanisms. The key personnel were identified as being: designers, design managers, production engineers, methods engineers, production managers, general managers, and personnel from the finance, marketing, sales, and R & D departments.

2.11.4 Co-ordination: Hindrance & Improvement Factors

Design - production co-operation and co-ordination was also investigated. Firms were asked to classify their degree of co-ordination and co-operation between design and production functions. Further, the factors which hindered or improved them were also examined. From the literature the important factors were: different expectations, departmental barriers, physical separation and personal relations.

Fig 2-13 Simultaneous Engineering - the Overlapping Concept



2.12 The Consideration of Production

The consideration of production takes two forms: the actual production aspects considered, machining etc, and the personnel able to bring their production knowledge into the design process. First of all a conception of manufacture was developed, Figure 2-13. It was realized that manufacture consists in either the external supply or internal manufacture of components. Components are assembled into sub assemblies, which are themselves assembled into fabrications using fixtures (screws, welds) Components are machined, moulded, extruded, forged etc from these and other such basic processes. There are also a number of parameters outside of these actual manufacturing techniques: stock, work in progress, machines (capacity, utilisation), plant and labour (skills, cost). This conception along with the literature was used to construct a list of significant manufacturing techniques.

2.12.1 Production Aspects

From the literature on production engineering and manufacturing a list of possible production processes and production considerations was drawn up. These were derived from the work of Blackburn et.al (1985), King (1985), Hayes & Wheelwright (1984), Pawar (1985), and Pawar & Riedel (1990). A characterisation of possible production processes is shown in Table 2-3 and the list of production considerations is shown in Table 2-4, below. The final list of production aspects was selected after some thought and in the light of results from issuing a pilot questionnaire. Blackburn et.al (1985) point out that despite the wide variety of manufacturing processes carried out (forming, casting, welding, cutting, surface finishing, making tools, jig and dies, and assembly) it is metal cutting which is the major activity. Haeusler (1981) offers a somewhat different picture stating that in the mechanical and electrical engineering industries about 50% of the work force is employed in assembly. And that costs and production times are determined to a large extent by the assembly process. Hence, the pilot questionnaire made an attempt to characterise the manufacturing operations of companies. The aim was to use this characterisation to classify firms into groups using particular techniques and then produce specific recommendations for each group to improve product design. The pilot questionnaire included a question derived from the list of possible production processes. The purpose of the question was to determine the capacity and utilisation of production processes used by companies. The pilot questionnaire was administered to industrial engineering students who can be expected to have a high degree of knowledge about production processes in use by their firms. Discussing this question with the respondents revealed two main difficulties with it - it was too complex and unnecessarily lengthened the questionnaire. It was, therefore, chosen to adopt the simpler approach of asking about the consideration of production aspects, rather than to determine from firms' processes what they should consider and when. This means that production considerations are examined by proxy, but it was felt, given the constraints on the research, that this was reasonable.

After some consideration the production aspects were narrowed down to: production processes, plant, production machinery, assembly techniques, labour requirements, materials, compatibility with existing products, production control, product quality and standardisation. It should be noted that this choice was limited due to the use of a questionnaire as the research instrument. For instance, labour requirements can be broken down into two: skills of workers and numbers of workers available. Notwithstanding this limitation, the research, importantly, sets out to identify in which stage of the design process these production aspects are considered. This information can then be used to formulate recommendations as to which aspects of production should be considered and when. It was decided to include other non-production aspects in the question in order to test the relative importance of production factors. These non-production, design, factors were: product cost, development cost, functional requirements, engineering design and style/ appearance.

Figure 2-14 Conception of Manufacture

- Manufacture
    - Sub-assembly
    - Assembly
        - Fabrication
        - Machining
        - Forming
        - Fastening
        - Finishing
        - Testing
        - Despatch
        - Component
            - Bought-in
            - Manufacture

Parameters: stock, machines (utilisation), labour (skills, cost, numbers), WIP, Plant.

Table 2-3 Manufacturing Processes: An Attempted Characterisation

Material Formation
- Rolling
- Spinning
- Extrusion
- Drawing
- Casting
- Moulding
- Powder metallurgy
- Forging
- Pressing
- Explosive forming
- Vacuum forming

Machining
- Turning
- Milling
- Planing
- Broaching
- Drilling/reaming
- Tapping
- Punching
- Chemical machining
- Spark erosion
- Grinding

Finishing
- Heat treatment
- Hot & cold working
- Electroplating
- Dipping
- Enamelling
- Spraying
- Coating
- Shot/sand blasting
- Polishing
- Honing & Lapping
- Anodising

Assembly

Impermanent	Screws/bolts
	Springs
	Clips
	Fasteners
	Plugging
Permanent	Welding
	Brazing
	Soldering
	Riveting
	Bonding
	Gluing
	Sintering

Group technology

FMS

Table 2-4 Production Aspects for Consideration

Production facilities & techniques
Processes (in/out/new)
Plant (cranes etc) (in/out/hire/new)
Machinery (number, capacity) (in/out/new/hire)
Assembly techniques
Labour skills and numbers
Existing products
Standardisation
Production control
Materials (choice, handling, storage)
Storability
- Warehousing
- Work in progress
- Final product

Transportation
Costs of work in progress
Packaging
Servicing

2.12.2 Influence of Production Personnel

The research also seeks to identify the extent of involvement of production engineering personnel in each stage of the design process. This, again, can be used to produce guidelines. The design stages were those already identified earlier in the chapter. Also, the research needs to consider the influence production had over design. This would be investigated by asking if production engineering had a say, or veto, over designs in progress. Secondly, if a design freeze was operated, after which no further design changes were possible without going through a formal change procedure.

2.13 COMPUTER-AIDED DESIGN

This section presents the literature review and theoretical investigations of the role of computer-aided design in the design process and the design - production interface. This is done in two parts. The first part examines the distribution of CAD in industry as a whole. It does this to both examine the diffusion of CAD in the mechanical engineering industry and to compare the diffusion with other industries. This latter will give a measure of the importance of CAD in mechanical engineering. The second part examines the impact of CAD upon the design - production interface.

2.13.1 Summary

Computer-aided design (CAD) is an important technology which has the potential to greatly influence the design - production interface. It is for this reason that the research considers the use of CAD. The research is designed to fill a gap in the literature between two important studies. The first of these is the UK national survey of microelectronics use in industry carried out by the Policy Studies Institute (Northcott & Walling, 1989). This survey, while determining the extent of CAD use in mechanical engineering (and particularly the number of workstations in use), does not identify what the CAD system is used for. The second study by Senker & Arnold (1982) and Simmonds & Senker (1989), on the other hand, while identifying some of the uses of CAD, does not cover a large enough number of firms, to enable statements about industry usage of CAD to be derived. The research here is thus designed to overcome the limitations of these two studies. The Senker study is useful in reporting that, at that time, CAD use was restricted to drawing only and that the more advanced features and possibilities of CAD were not used. The research is designed to test this hypothesis for the mechanical engineering industry.

As a first step the research attempted to identify the proportion and characteristics of firms using CAD. The size (employees, turnover), region and age of production equipment etc. This will be used as a comparison with the PSI survey. Second, the types of use that firms make of CAD will be analysed. This considers whether new, old or both types of designs were put onto the CAD system when purchased.

What types of designs were performed on the CAD system: 2D, 3D and solid modelling were examined. What types of design analysis: finite element, machining simulation, component interference checking and conceptual design were carried out. The research also investigates in which stage of the design process CAD is used. It considers whether CAD has affected the degree of co-ordination and integration between design and production in the design process. It also asks whether production engineering have access to the CAD system. Lastly, the research seeks to identify the achieved benefits of CAD, and which benefit users thought was the most important. These results will form an important contribution to knowledge. They will be used to formulate guidelines for CAD use.

2.13.2 What is CAD

The acronym "CAD" stands for Computer Aided Design. It thus connotes that computers are used in assisting the design process. Most frequently CAD is associated with the drawing office and Computer-aided Draughting. This is a somewhat restricted view of the use of computers in the design process. The use of computers in the design process covers a wide range of activities, some of which are: various forms of Finite Element Analysis, for example, stress or magnetic calculations; simulation of machining; compilation of bill of materials; etc. The definition given by Bessant and Cole (1985) is:

> Production design and analysis including graphic design, functional analysis, stress and strain analysis, heat and material balances, simulation and modelling, data reduction and analysis and cost estimating of the proposed product or system to determine fitness for purpose and economically optimised production. (p73)

A further definition given by the EEC is: "The capability of a computer to be used for automated industrial, statistical, biological, etc., design through visual devices." (Commission of the European Communities, 1986 p137-8)

Computer-aided Draughting is an important aspect of CAD because it directly interfaces the design and manufacturing processes. When components are designed on the CAD-Workstation the parts database can be used to determine if a component used previously can perform the same function as the new one. This greatly reduces the design time of components, but also reduces manufacturing difficulties, particularly if the component is already in production or was previously produced.

Having provided an idea of the capabilities of CAD, two questions remain. First, how far has usage of CAD spread in manufacturing companies and second, what is the impact of CAD upon the design - production interface. We will come to the latter issue in section 2.14, first we shall consider the distribution of CAD. The Policy Studies Institute have carried out a regular biannual survey of the use of microelectronics over the period 1981 to 1987. The discussion below is based on the figures given in the PSI surveys, augmented by appropriate alternative sources.

2.13.3 Details of the PSI Survey

The PSI survey is based on a survey of 1,200 manufacturing industry establishments. It was conducted by telephone with the managers, or heads of establishments for small firms, responsible for the introduction of new technology. The survey sample was matched to the distribution of establishments across employment size and between industries, with regional distribution also influencing sample choice. Each of the initial firms chosen in 1981 was selected at random. In forthcoming survey years an attempt was made to use the same firms as in the previous survey. The survey thus provides a representative sample of UK manufacturing establishments, and a firm basis on which to base estimates of the change of use of microelectronics over time. (See Northcott & Walling, 1988 p25-6).

The PSI surveys detail the use of microelectronics in manufacturing industry. As the concern of this research is with design and production the statistics taken from the reports are those that refer to company establishments which are using microelectronics in their production processes. Thus, products containing microelectronics are not mentioned below. Obviously, CAD will only affect production processes in terms of usage figures. It was also desired to gain a picture of the national situation, and so figures which have been weighted for all UK manufacturing establishments (ie. plants, branch plants etc.) will be presented. All the figures quoted below are given in the statistical appendix (Appendix D) - cross referenced here by D-table number.

2.13.4 Distribution of Microelectronics

Before dealing with the distribution of CAD it is interesting to look first at the usage of microelectronics in manufacturing industry. This is to demonstrate that the figures for CAD are not unusual and conform to the pattern of usage of microelectronics in industry in general. Consideration of the use of microelectronics in manufacturing establishments (Table D-1) shows that over the six year period, 1981 to 1987, usage of microelectronics in production processes has increased from 34% of surveyed factories to 77% of surveyed factories. This represents a national increase, over the same period from 18% to 59%. We can thus be confident that microelectronics have had an impact nationally upon production processes. The next question is where has this impact been greatest? - large or small firms, which industry and which geographical area.

Table D-2 shows the impact of microelectronics for size of establishment. This shows large plants (1,000 or more employees) having a consistently high use of microelectronics (90+%) from 1983, reaching 99% by 1987. Plants in the 200 to 1000 size range also reached usage rates of 90% by 1987. Those in the size range 100 to 200 have rates of 75% in 1987 from 25% in 1981. The 50 to 100 size firms have also caught up from 18% in 1981 to 60% in 1987. Very small firms, 20-50, have gone from 8% in 1981 to nearly 50% in 1987. Thus plants of all sizes have 1987 usage of 50% or greater, with high rates, 75% and then 90% for plants of 100+ employees. Thus microelectronics have significantly impacted upon plants of all sizes.

Turning to the impact upon industry (Table D-3) we find that in 1987 all industries have microelectronics usage rates greater than 60%. Clothing, Textiles, and Other manufacturing have rates in the 60s. Mechanical engineering, Vehicles, and Metal goods have rates in the 70s. Food and drink, Chemicals and metals, Electrical engineering, and Paper print have rates in the 80s. A survey of innovation by Oakey et.al. (1980) found that industries which had a high level of innovation were mechanical and electrical engineering and scientific instruments. This confirms that these industries are high utilisers of new technology.

The geographical impact of microelectronics in 1987 (Table D-4) has been greatest in Yorkshire-Humberside 83%, North West 81%, with South East, South West, East Midlands, Scotland and the North all 75% and lastly West Midlands with 70%. The figures of 81 and 89% for East Anglia and Wales are misleading because of the small number of process applications - 36 and 35 respectively. Therefore, microelectronics has significantly impacted on over two-thirds of plants in all regions with the exception of East Anglia and Wales. The survey by Oakey et.al. (1980) found that regions with above average innovation rates were East Anglia, South East, South West and the North. The number of small and large plants innovating in the South East compared with its industrial structure was very high. In terms of absolute numbers of innovations the South East, North West and West Midlands were top, with Wales bottom. These results confirm the PSI results.

2.13.5 Distribution of Microelectronics in Design

The information about the use of microelectronics in production processes does not tell us what type of microelectronics are used and in which parts of the production process. The PSI surveys have also asked about the type of production process in which microelectronics was used. Design forms one of the categories that they asked about. Table D-5 shows the use of microelectronics in the design function of manufacturing industry. Tables D-6 to D-8 show the distribution of microelectronics use in design by size, industry and region. This shows that a third of the surveyed factories are using microelectronics in their design function. This represents just 17% of UK manufacturing establishments. This is a three-fold gain on the figure for 1983. Once again a half to two-thirds of large plants (500 employees plus) use microelectronics in design. A third of medium sized plants, a fifth for plants of size 100-200 and 10% to 15% for small firms. Very small plants (less than 20 employees) trail with only 5%. Therefore, medium and especially large firms are using microelectronics in design

The industries most impacted by microelectronics in design are: electrical engineering and vehicles both 64%, mechanical engineering 50%, Chemicals-metals 30% with the rest below 20%. Regionally, the South West, 40%, leads with all the other regions 30 to 35%. Thus at least a third of all plants across the country are using microelectronics in design. With at least a half of engineering and a third of Chemicals-metals being users.

2.13.6 Distribution of CAD

The question then arises as to what type of microelectronics these firms are using in their production processes. The PSI also asked what type of microelectronic equipment was used. Table D-9 shows the usage of CAD workstations from 1983 to 1987. A third of sample establishments were using CAD workstations in 1987 - a doubling over 1983. However, only 17% of UK establishments were using CAD workstations. The percentage figures for microelectronics use and CAD workstations are numerically similar thus implying use of microelectronics in design means use of CAD. Over the same four year period to 1987 the PSI estimate that the number of CAD workstations in the UK grew from 9,000 to 21,000, again more than doubling (Table D-10). Thus CAD workstations have not had a major impact upon all UK manufacturing establishments as only a fifth of establishments have them. However, growth rates of CAD use are relatively high at 6% every two years.

As a comparison to the PSI figures we can turn to other sources. Owen (1982) says that in the early 1970s CAD and CAM was simultaneously introduced into the drawing offices of the large aerospace, shipbuilding, electronics and automobile industries. The number of systems then in existence was 200. By the end of the 1970s the number of workplaces using CAD/CAM had increased to 12,000. The Department of Trade and Industry were quoted by the EEC as indicating that there were 1,000 CAD systems of all types, including micro-based systems, by mid 1983. A further source, CADSource Ltd., was quoted as estimating the number of systems in September 1983 as 1,410 (excluding micro-systems, but including construction industry use). (Commission of the European Communities, 1986 p126). These figures seem rather low compared to the PSI ones and of course they are older and thus do no tell us anything about the current situation.

It remains to be seen where CAD is used in terms of size, industry and region. In terms of size (Table D-12), again very large plants (1000+) dominate, with nearly two-thirds of them using workstations in 1987. Half of large plants (500-1000) and a third of medium sized plants also use them. For small firms usage drops from a fifth of 100-200 to 10% of 20-49 sized employee firms. Only 4% of very small firms use workstations. Over the period 1983 to 1987 usage rates have more than doubled for small firms but more than tripled for large firms (200+ employees). Thus CAD workstations have had the most impact upon medium sized and large firms. Northcott & Walling point out that the proportion of CAD users "is higher in the larger plants but, because there are far more of the smaller plants, the total population of these kinds of equipment is distributed in broadly similar numbers between all the six size bands of plant in the survey" (1988, p65).

CAD workstations are most heavily concentrated in vehicles 68%, electrical engineering 52% and mechanical engineering 41%. In the three year period to

1987 vehicles and electrical engineering doubled their usage rates, while mechanical engineering had a five-fold increase. Chemicals-metals have a third usage but all other industries only have a fifth (Table D-15). Northcott & Walling also point out that CAD is also particularly common in the electronic and instrument engineering industries (1988 p65). Regionally (Table D-16) the usage rates are very similar. They range from East Anglia 22% to East Midlands 37%, with most regions having rates of at least a third. Northcott & Walling conclude that the regional distribution of workstations is less marked than the industrial distribution and tends to reflect the industrial structure of Britain (Northcott & Walling, 1988 p64-5).

A further analysis of CAD workstations per user establishment has been carried out by the PSI (Table D-11). This shows that although the number of user establishments increased over the four year period, 1983 to 1987, the number of workstations per establishment have remained relatively constant. For example, the percentage of establishments using a single workstation actually decreased a little, from 33% to 27%. Establishments using two to ten workstations stayed constant at 56%. There was a slight increase in establishments using 11 to 50 stations, from 12 to 15%. Likewise, there was a one percent increase in the number of establishments using 50 or more workstations. This figure is quite significant given the small number of establishments using such a large number of workstations.

Again the number of CAD workstations can be analysed by establishment size and industry (Tables D-13, D-15 & D-17, respectively). These figures are weighted for UK manufacturing establishments, and are given in thousands. Table D-13 shows a consistently high use of workstations by very large (1000+) firms from 1983 to 1987, at 4 to 5,000. However, from a base of 1,000 stations per size band in 1983 usage has almost caught up to the rates of very large users. They thus range from 2 to 4,000, with most being 3,000. Even very small users had a total of 2,000 stations between them in 1987.

Most industries have 1,000 CAD workstations. Paper print have 3,000, from 2,000 in 1983. Vehicles leapt from 1,000 to 4,000 from 1985 to 1987. Likewise, in the same two year period, mechanical leapt from 1,000 to 3,000 and electrical from 3,000 (1983) to 6,000 (1987) (Table D-15). Regionally the South East shows the almost consistent highest number of CAD workstations, from 2,000 equal with West Midlands in 1983 to 6,000 in 1987. The West Midlands remains at 2,000 while North West, East Midlands and South West move from 1,000 in 1983 to 3,000 in 1987. The remaining regions only have 1,000 workstations.

2.13.7 Percentage of Production Processes Using CAD

The final analysis that the PSI carried out was to determine the extent of processes which used CAD (Table D-18). This analysis shows that 29% of surveyed establishments used CAD for 1 to 10% of their production processes, 48% of establishments used CAD in 11 to 50% of processes and 39% used CAD in more than half of their processes. Thus almost a third of surveyed establishments used CAD in very few of their processes. Half the establishments used CAD in a minority of their processes, while 40% used CAD in the majority of their processes.

2.13.8 Comparison of CAD and Microelectronics Use

In 1983, 55% of surveyed establishments were using microelectronics in their production processes but only 10% were using CAD workstations. Nationally the respective figures were 37% and 6%. By 1987 microelectronics use had increased to 77% of surveyed establishments and CAD to 31%. Nationally the figures were 60% and 17%. Thus growth of both microelectronics and CAD over the four year period has been the same at 20%. Nationally the growth rate has been 10%. Thus the growth in the use of CAD has kept pace with the adoption of microelectronics in production processes and thus the preceding analysis for CAD usage does not diverge from the general picture for microelectronics.

2.13.9 CAD & Batch Manufacturing

Unfortunately the PSI survey does not analyse the type of production technology (unit, batch & process) used in industry. Thus it cannot be used to make statements about batch manufacturing. The PSI survey does not give enough details of surveyed firms in order to be able to construct a proxy measure to use as indicative of batch. Size of firm is ruled out as a proxy measure, because, as Woodward (1980) found, both large and small firms use each of these production technologies. This is confirmed by considering the case of British Aerospace a large firm which makes heavy use of batch manufacturing. Thus we have no information about CAD usage in batch manufacturers.

2.13.10 Distribution of CAM - CNC

Usage of CNC machine tools has grown in surveyed factories from 18% in 1983 to 28% in 1987. Nationally the growth was from 14% in 1985 to 18% in 1987. The number of CNCs has nearly doubled from 1983 to 1987 (Northcott & Walling, 1988 p64, 151).

Most establishments (60%) have between two and ten CNC machines, while factories with one and factories with 11 to 50 both comprise a fifth of establishments. This usage rate is the same for 1985 and 1987 (ibid, p152). Once again large firms dominate with 36 and 55% of surveyed factories of the top two size bands having CNC. Medium sized firms have a third users, small firms of 50 to 200 employees have 20% usage rates and very small firms on 14%. Growth of use has been roughly ten percent over the period 1983-7 for each size band (ibid, p157). Northcott & Walling comment that as with PLCs and CAD the proportion of CNC users "is higher in the larger plants but, because there are far more of the smaller plants, the total population of these kinds of equipment is distributed in broadly similar numbers between all the six size bands of plant in the survey" (1988, p65).

CNC is concentrated in the mechanical engineering and vehicles industries (60%), with electrical engineering and metals-goods having usage rates of 40%. All other industries have rates below 15% with the exception of other manufacturing with 29%. Growth over the period 1983 to 1987 has been highest in the dominant industries at 20% with the secondary users growth at 10%. Regionally, there is an approximately constant usage rate of 25 to 30%. The West Midlands showed the highest concentration at 36%. Again as for CAD the figures for East Anglia and Wales are misleading due to the small number of users. Growth has been roughly 10% in all regions. (ibid, p158)

2.13.11 Distribution of Other AMTs

The type of advanced manufacturing technology (AMT) in widest use is PLCs (programmable logic controllers), used in 1987 by nearly a half of surveyed plants and nearly one third of UK manufacturing plants. PLCs are mainly used to control or monitor a single process or machine. Although the number of robots in use has doubled both these and simpler pick and place machines are used by only a minority of plants - 2 and 5% respectively. PLCs are particularly common in the food and drink and chemicals and metals industries (ibid, p64-5).

2.13.12 Limitations of the PSI Survey

A number of limitations with the PSI survey are identified below and their impact upon the preceding analysis considered. As Northcott, the person most involved with all the surveys, points out they do not "take account of the extent or quality of use involved in a particular application" (Northcott, 1986 p34). Hence, the degree to which a CAD system is used (on a number of dimensions - workstation utilisation, amount of design work done on CAD etc) is not indicated. Secondly, for process users "some applications are relatively simple and limited while others are more complex or ingenious or for other reasons make a greater difference to productivity or product quality. They also take many different forms, with varying implications for both implementation and effects" (ibid, p35). He points out that it was not possible for the PSI to measure these kinds of differences using a single yardstick because the kinds of processes are so varied across the range of manufacturing. Further, some differences are qualitative and do not lend themselves to any universal unit of measure (ibid). This latter objection would be lessened if one were carrying out a survey into the uses of a single type of microelectronics, eg. CAD. This is surprising because the PSI attempted to measure the benefits of various types of microelectronics in 1987 but it excluded CAD! (Northcott & Walling, 1988 p171).

Somewhat more seriously the PSI have neglected to analyse failure of microelectronics implementation, even though they asked about it (Northcott & Walling, 1988 p271). Thus all the PSI figures refer to successful implementations (of uncertain quality) and do not indicate the degree of failure and difficulties of implementing new technology. Also the respondents may filter the truth from the researchers by reporting excellent results to cover up failures or mistakes.

Also in making comparisons across industries the headings used by the PSI cover a lot of industries. Thus the vehicles classification previous to the 1980 SIC contained aircraft, cycles, motor cycles and railway equipment. In 1980 these industries were moved into the other transport equipment to be with shipbuilding. So although they were in vehicles just because the car industry is susceptible to CAD adoption does not mean to say these industries would be. Thus the vehicles category could distort the actual CAD usage rates. Also in 1980 a new class of office equipment and electronic data processing was created.

2.13.13 Summary of Distribution of CAD

Although the impact of microelectronics upon manufacturing industry has been great particularly in electrical and mechanical engineering, the impact of CAD has been less marked. Despite growth rates of six per cent every two years CAD has had a less marked effect. In electrical and mechanical engineering usage rates were 52% and 41% respectively. The regional distribution of CAD workstations remained approximately the same, and tended to reflect the industrial structure of the UK, rather than any inherent regional difference. The actual number of CAD workstations in use grew from 9,000 in 1983 to 21,000 in 1987. This growth is largely accounted for by the number of user firms increasing, as the number of workstations per firm has remained relatively stable over the period.

Unfortunately, the PSI survey does not give us any indication of the use of CAD by batch manufacturers. Neither does it give any indication of the uses to which CAD is put or the quality of its use. However, with these caveats in mind it showed that CAD use has been significant in both electrical and mechanical engineering. As a final note the Department of Trade and Industry ceased funding the survey in 1987 and so no further national surveys of CAD or microelectronics use will be forthcoming, which is a pity.

2.14 The Impact of CAD on the Design - Production Interface

This section discusses the impact CAD has on the design - production interface. The first issue to consider is what type of firms would use CAD, or rather what are the barriers to its adoption. Automation of machining and assembly operations will have little impact upon batch manufacturers. This is because as Blackburn et.al (1985) state that batch production has been an obstacle to the introduction of integrated processes, and heavy investment in automated equipment cannot rapidly be recovered. This is particularly the case with small batch production where the time taken up between runs in resetting machines, or even reorganising the factory layout, precludes rapid recouping of the investment. Batch production also introduces constraints into the operation and development of production machinery (ibid). Small batch production is even more of a barrier to the introduction of new technology. This would lessen the adoption of CAD by smaller firms and batch manufacturers.

The highly functional specialisation of British industry creates an organisational environment in which the full potential of new manufacturing technology is inhibited (Child, 1987). This acts as a barrier to the introduction of integrative technologies such as CAD/CAM, and of course hinders attempts to integrate design and production. One study found that CAD did not increase the amount of interdependence of designers with manufacturing (Majchrzak, 1988). In a second study CAD did affect interaction between the two departments. Specifically, "for non-users, their discussions with manufacturing were primarily routine and conducted in a fashion similar to the sequential nature of traditional design work. For CAD users, their discussions were more iterative and unpredictable in which the perceived joint needs of manufacturing and R&D were shared" (Majchrzak, Mosher & John, 1988). Majchrzak concludes that "CAD has definable effects on perceptions of job autonomy and teamwork; however, some of these effects, such as conversations with manufacturing personnel, are clearly a function of how the organisation uses the technology to foster engineering-manufacturing discussions" (Majchrzak 1990). As a strategy to overcome this resistance to integration both Child (1987) and Campbell & Warner (1988) recommend the use of an incremental or piece-meal approach to implementation. This would facilitate a learning process which would encourage people to accept the technology and its integration of functions.

From the above analysis the characteristics of firms who were using CAD was derived. Characteristics were chosen to allow meaningful conclusions to be drawn about CAD use. For example, in terms of company size - employees (on site and in the company) and turnover. Firms can be characterised by their regional distribution, by establishment employee size, by sales turnover, by the age of production equipment, by type of process technology (one-off, batch, and mass/line) and finally by type of product manufactured (intermediate, final, both or consumer).

2.14.1 Firms' Use of CAD

While CAD/CAM has capabilities to bridge the interface between design and manufacture a CAD system bridges the gap between designers and draughtsmen within the design department. CAD thus slots into the grey area that exists between these two sets of employees (Campbell & Warner, 1988). CAD has the potential to do away with the division of labour, and almost make the draughting function redundant. This is particularly the case as the CAD system is up-graded to include more computer-aided engineering, thus implying the merging of draughting into the design engineers' sphere (ibid). Thus a study by Majchrzak (1988) showed that designers using CAD experienced more teamwork and slightly more non-routine work but similar amounts of autonomy as do non-CAD using designers. However, draughtsmen using the CAD system tended to input old designs and experience less teamwork, less non-routine work and less autonomy than non-CAD draughtsmen. Thus the longer CAD is present in the organisation, after old designs have been entered into it, the more likely that draughtsmen will have been made redundant or had their jobs changed. The extent of this will depend upon how the CAD system is used within the firm. If it is used simply as a replacement for drawing then the effect on draughtsmen will be less marked. Thus, what type of designs (old, new or both) are put on the system is an issue for investigation.

It can be seen that the two barriers to CAD adoption and the way it is used greatly affect the impact of CAD upon the design - production interface. It is thus the case, in this context, that although CAD has become more sophisticated (3D and solid modelling and stress analysis) these uses do not account for the most widespread use of CAD. The study by Arnold & Senker (1982) showed that most systems are used for drawing and thus it would be better to think of CAD as computer-aided <u>drafting</u>. This was confirmed again by Simmonds & Senker (1989) in their longitudinal case studies of firms, it was reported that CAD use was mainly restricted to drawing only and that the more advanced features and possibilities of CAD were not used. Blackburn et.al (1985) argue that this would be the case for batch engineering given its lag behind other sectors of engineering in its use of CAD. In batch engineering, CAD is especially appropriate for the modification of existing designs, more than for designing entirely new products. It thus facilitates the customising of products, which according to Blackburn et.al is what characterises much of the work of the mechanical engineering industry. The hypothesis that CAD is only used for drawing will be investigated by the survey. And also the type of drawing done - 2D or 3D will be investigated, the hypothesis being that 2D would predominate.

2.14.2 Advanced Use of CAD

This section examines the advanced uses of CAD, in use and future potential. It does so by comparing the use of CAD in the electrical and electronic industries with that in mechanical engineering. The electrical industries present a much more fruitful case for the use of computers, both in design and manufacture. In the electronics industry computers can be used across the spectrum of design and into the manufacturing process (Stovey, 1982). In design computers can be used from the initial stages of functional design of the product to design of the Printed Circuit Board (PCB) layout. In functional design computers can be used to explore new designs with the designer experimenting with designs. Secondly, libraries of past designs and standard designs can be incorporated into the new design. Once a functional design has been produced the computer can simulate the operation of the design to check that it will work when actually built. This simulation is called logic simulation - the operation of the logic of the design is simulated. Thus a products function can be tested before it is built.

Having produced a correct functional design the designer can move to construct the physical circuit. The first stage in this process is to produce a circuit layout on a PCB. The computer can again be used to situate components on the board, following certain rules for positioning of components etc. This process can be manual or automatic. The computer can then draw the electrical connections between the components, this process is referred to as circuit layout. This is quite a complex problem and can produce PCBs built like a sandwich that have very many layers of connections, eg 20. The layout diagrams can then be drawn onto masks which are used in a photographic process to manufacture the final PCB. Once a PCB has been manufactured instructions from the design computer can be used to drive automatic insertion machines. These automatically insert the required components in the correct place on the PCB. The more advanced machines can automatically select the correct component to insert from a stock of standard components. Once the components have been inserted the PCB is fed through a flow-soldering machine which effects the physical-electrical bond between the board and the components. The completed PCBs can be tested on automated test equipment.

Hence, it can be seen that the whole electronic design process can be highly automated from design to manufacture and test. Most electronic products, however, require some mechanical engineering of the packaging of the product. The PCBs have to be inserted into a frame which is contained in either a metal or plastic casement. This added mechanical engineering may not be as computerisable, or automatable, as the majority electronic content of the product. In electrical engineering the situation is worse than in electronics. Here the mechanical content of the product is much higher. Thus PCBs may not be used, instead wire frames may used. These are, almost without exception, assembled manually by skilled wire-wrappers. Conventional mechanical engineering CAD approaches thus have to be applied, not only to the casement, but also to the design of the wire frames. Hence, the use of CAD in electrical engineering would thus be less than in electronics.

A lower level of microelectronics use in mechanical engineering was found by the PSI microelectronics survey. This survey showed that electrical engineering has consistently higher rates of microelectronics use than mechanical engineering over the period 1981 to 1987. This higher use of microelectronics means a greater proportion of electrical engineering production processes are automated. Similarly, the use of microelectronics in design is consistently higher, electrical engineering increasing from 47% in 1983 to 63% in 1987, while mechanical engineering increasing from 27% to 50% over the same period. The use of CAD workstations show a similar pattern with electrical engineering usage increasing from 26% to 52% and mechanical engineering increasing from 8% to 41% over the same four year period. The 1987 number of CAD workstations is double in electrical as in mechanical engineering at 6,000 (Northcott & Walling, 1988).

The potential benefits of the use of CAD in mechanical engineering are great. This is illustrated by the growth of CAD workstation use since 1983 being 33%, while the comparable growth in electrical engineering being only 26% - the latter only a doubling (ibid). In mechanical engineering computers have the potential, just as in electronics, to be used across the design spectrum from functional design to manufacturing simulation. Computers can be used for the analysis of mechanical engineering systems, eg. kinematic analysis. Also finite element analysis can be combined with 3D CAD systems to model the stress, thermal and deformation of components. As an example Port et.al (1989) cite Northrop's B-2 Stealth bomber. The whole bomber was conceived, engineered and produced totally by computer. The computer model is so detailed that Northrop did not bother building a mock-up. All but 3% of the bomber's parts fitted together the first time, previously the best the company had achieved was 50%. Moreover, there was a reduction of 6-to-1 in engineering changes during the design, with those that were made being done five times as fast as normal. The research sought to determine how far mechanical engineering companies had achieved this potential.

As in electronics once a correct functional design has been produced it can be translated into production. A key application is the simulation of the path that the tool of a machine tool would travel in machining the 3D design. This simulation can obviously ensure that the component can be made on any given machine tool. This latter radically reduces the lead time to get a component into production and eliminates prototyping. There is the potential to use artificial intelligence in the manufacturing process. Specifically, in the design of components in order that their design is oriented towards automatic handling in automated assembly machines. This technique is documented by Swift (1987). It involves the capture of design rules for assembly-oriented design from a human expert and their inclusion into a computerised expert system. This expert system is connected to a CAD system on which the component has been designed. The expert system then analyses the design held on the CAD system (ie. an automatic process) and produces suggested modifications to the design to improve its assembly orientation. This is done in an interactive manner with the designer present and the expert system drawing its suggested modifications onto the screen. The expert system implemented by Swift had an extremely high efficiency, achieving rates equal to that of the human expert for the majority of components, and only being slightly out-performed (5%) with difficult components. A similar system was used by NCR in the manufacture of its latest computerised cash register. This cash register was marketed just two years after design began and can be assembled in two minutes - blindfold (Port et.al, 1989). The 3D model of the components were analysed by computer and a simulated assembly of the product being done on computer. This ensured they would fit together, and reduced the parts count from 23 to 15. The ease of assembly is accounted for by there being no screws in the design. The advanced uses of CAD in manufacturing are thus open for investigation.

From this analysis of the potential advanced uses of CAD the research examined the following: design analysis (finite element analysis), component interference checking, design for assembly, design for automatic assembly, expert systems (these two taking up Swift's point mentioned earlier), the use of CAD for conceptual design: mechanical/ kinematic design, its use for compiling bills of material, die and tool design. Also the integration of CAD into production was examined by asking about the use of CAD to simulate machining and tool path nesting.

The use of CNC machine tools, whether 3 or 5 axis machines was also investigated. Also the size of establishment was cross checked against CNC use to see if usage increased with firm size (a reasonable hypothesis).

A further question in the use of CAD is when is the system used. The design process is a linear staged process moving from feasibility study, product specification, design and development through to eventual manufacture. As discussed above CAD and CAD/CAM have greater effects on design and manufacture than the earlier stages of the design process. Therefore, CAD will have little effect on the product specification stage. This hypothesis would be modified if a highly integrative CAD/CAM system were in use. In this case the specification could be drawn up to reflect the capabilities of the system. However, as discussed above, the presence of such systems in industry is not common and their use in fully integrated contexts is even more uncommon. The research looked into the stage during the design process when CAD was used, using the same stages as identified in the Product Design Process section (2.7).

Finally, CAD can also lead to improvement through better co-operation between design and production personnel. If designs could be produced which were easier to manufacture this would result in reduced lead-times and lower production costs. To test this questions were asked if CAD had increased integration and co-operation between design and production. Also respondents were asked if production engineering had access to the CAD system.

2.14.3 The Benefits of CAD

From a review of the literature it was found that the use of drawing productivity in measuring the gains of CAD is irrelevant. This is the case despite its continuing use by managements as a justification for the investment in CAD (Currie & Campbell, 1988). The realisation of a higher number of drawings per person is something which CAD rarely delivers and which, in any case would represent the most modest benefit of all (ibid). Many studies report the gains of CAD as arising from: improved quality, rapidity of design (lead times), ease of modification, shortening of development cycles, customisation and sophistication of products (meeting customer needs), repeat designs, better presentation of tenders, need for increasingly complex products and increased quality and clarity of drawings (Campbell & Warner, 1988; Blackburn et.al, 1985; Arnold & Senker, 1982; Ingham, 1989). The research, therefore, asked firms to state the achieved benefits of CAD, from the following list: ease of modification, rapidity of design, shorter lead times from initial stage to commercialisation; Other more manufacturing oriented benefits (which would reduce costs): simplify/ ease manufacture, simplify assembly and increase consideration given to manufacture and shorter production runs of products; Customer oriented benefits of increased customisation and sophistication of the product were also asked about. Users were also asked to rank these benefits in terms of importance - to check to see which was most beneficial.

2.14.4 Affect of Implementation Upon CAD Use

The process of implementation can affect the way CAD is used. For instance implementation strategies such as project teams may be inadequate to realise the benefits of CAD in everyday use. Secondly, a failed attempt to introduce a fully integrated CAD/CAM system all-in-one-go creates resistance from the affected groups, ie. draughtsmen and machine operatives, designers and production engineers. A piecemeal implementation gradually convinces people, by example, that they need CAD and they should not oppose its introduction. If this strategy was pursued it would lead to a more successful implementation and in the end a more fully integrated system (Lee, 1988). A decision was made not to investigate this issue, particularly as it would require a longitudinal methodology.

2.14.5 Summary

This section on CAD has reviewed the literature in two areas, the distribution of CAD in industry and its impact upon the design - production interface. The question to be examined for distribution was had the growth in CAD usage by firms continued. Also what was the level of usage of CNC machine tools. Next up for investigation were the characteristics of user firms - were some firms more likely to use CAD than others? In terms of impact upon the design - production interface the issues were: what was the CAD system used for (type of designs, type of drawings 2D/3D), what were the advanced uses (for design analysis, finite element analysis, component interference checking, design for assembly, design for automatic assembly, for expert systems, the use of CAD for conceptual design: mechanical/ kinematic design, its use for compiling bills of material, die and tool design, for simulating machining and tool path nesting. The question of when the CAD system was used would also be looked into. Importantly, the achieved benefits of CAD, particularly manufacturing-oriented benefits would be investigated. An attempt was made to measure the impact of CAD on design performance. This was done using the two measures identified earlier, modification and standardisation. The other organisational impacts of CAD measured were intended to determine if CAD had bridged the gap between design and production. These measures were production engineering access to the CAD system, and effect of CAD upon co-ordination and integration between design and production departments. If CAD could bridge the gap between design and production the potential competitive benefits of this are great. The survey for the first, in contrast to previous studies, sought to do this for the whole of the industry rather than a few case study firms.

This concludes the CAD section and the theory chapter. The chapter has reviewed the literature on the design - production interface, placing the study in context, put forward a theoretical framework for classifying approaches to studying design, and models of the design process. The four themes of the research were the examined: the product specification, organisation and co-ordination, the consideration of production and finally CAD. The next chapter presents the methodology of the research.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter outlines the research methodology and its effectiveness. The methodology adopted for the research was a novel two-pronged one. First, a survey of the mechanical engineering industry was undertaken. Second, a series of structured interviews of significant issues arising from the survey were conducted. The structured interviews were connected to the survey by an analytical bridge - the issue of design performance. Two sets of structured interviews were undertaken, one on CAD and one on design. Each set of structured interviews consisted of matched pairs of companies - one a good performer, the other poor. The firms were matched on product, turnover and employee size, as closely as possible. This produced eleven structured interview firms, five for CAD and six for design.

This methodology chapter is divided into three main sections. First, a review of the methodologies of previous studies. This draws on the limitations of these studies to derive the research design of the present study. Second, the methodology of the national survey is presented. This discusses the justification of the choice of the survey method, the selection of respondent, the questionnaire formulation, its wording, source of addresses, the sampling frame, testing the sample for bias, the process of selecting firms, determining the sendee, the limitations of questionnaires, the measurement of performance, the method used to analyse the questionnaires, the responses received and response rate, and finally the characteristics of the respondent firms. Third, the methodology of the structured interviews is presented. This justifies the structured interview method, relates how the two methodologies were linked, discusses the pros and cons of the adopted structured interview method, describes the process of selecting the structured interview firms, the process of carrying out the structured interviews, and gives the relevant details of the selected firms.

Table 3-1: Methodologies of Design Studies

Authors	Sample Selection	Size	Time Frame
Survey: Telephone Questionnaire			
Northcott - PSI & Walling '88	All Manufacturing Ind, Structured Representative inc. Mechanical Eng	1,000 200	Every two years '83 to '87
Survey: Postal Questionnaire			
Black & Baker '87	Scottish Engineering Ind & Textile Industry	42 19	snap shot
Service et.al '88	5 Industry Categories	369	Snap shot
Ughanwa & Baker '89	Queen's Award winners (self-selecting)	100	Snap shot
Walsh et.al '92	Domestic heating Office Furniture Electronic Business & Computing Equipment	10 21 20	Snap Shot plus 7 years financial data
Ingersoll Engineers '89	Med & Large Manufs Mechanical Engineering	264 32	Snap Shot mixed Ind sample
Black & Shaw '91	Engineering Co's Same system CAD users Mechanical Eng	24 18	Snap shot mixed Ind sample
Roy in Walsh et.al '92	Plastic Products Industry	49	Snap Shot + design & business performance analysis
Trygg '92	Swedish large machinery & metal working co's	109	Snap shot
Ettlie & Warner '92	Furniture, machinery elect & electron equip, transport equip, other (31 SICs in all!) Very large US co's	43	Snap shot
Survey: Interview Questionnaire			
Cooper & Kleinschm.'88	Computer, telecomms m/cery, components instruments, chemical electrical, instruments no selection criteria given	125	Snap shot Product pairs: success/fail
Hart et.al '89	Scottish Textile firms & engineering firms Judgementally selected	6 14	Snap shot
Potter & Roy '91	Design Consultant Users SMEs in 13 sectors of UK manufacturing (self-selecting)	90 Ints 130 postal Qs	Snap shot
Case Studies			
SAPPHO '76	Industrial innovations Chemical, Mechanical, Car, Electronics & Defence.	?	Snap shot, Product pairs success/fail
Pugh '90	Product Groups	~10	Longitudinal
Johne & Snelson '90	Selected Firms	11	Longitudinal
Takeuchi & Nonaka '86	Selected Firms	5	Snap shot
Roy '84	Bicycle Industry Austin Rover & Ford	12 2	Snap Shot
Hollins & Pugh '90	All UK manufacturers of selected products (not stated which or numbers)	?	Medium duration
Oakley '78	Individual Firm	1	Innovation cycle
Pawar '85	Individual Firms	20	Innovation cycle
Ettlie & Stoll '90	Individual Firms Misc. products & Co's	9	Innovation cycle
Trygg '92	Individual Firms Misc. products & Co's	14	Innovation Cycle
Hunt '91	Individual Firms Misc. products & Co's	11	Snap shot
Simmonds & Senker '89	Eng Ind CAD Users	14	Snap Shot
Mixed Methodology			
Riedel '90-93 (This study)	Mechanical Eng Industry (national, random) + 11 follow-up structured interviews	113	Snap shot

3.2 Methodology of Previous Studies

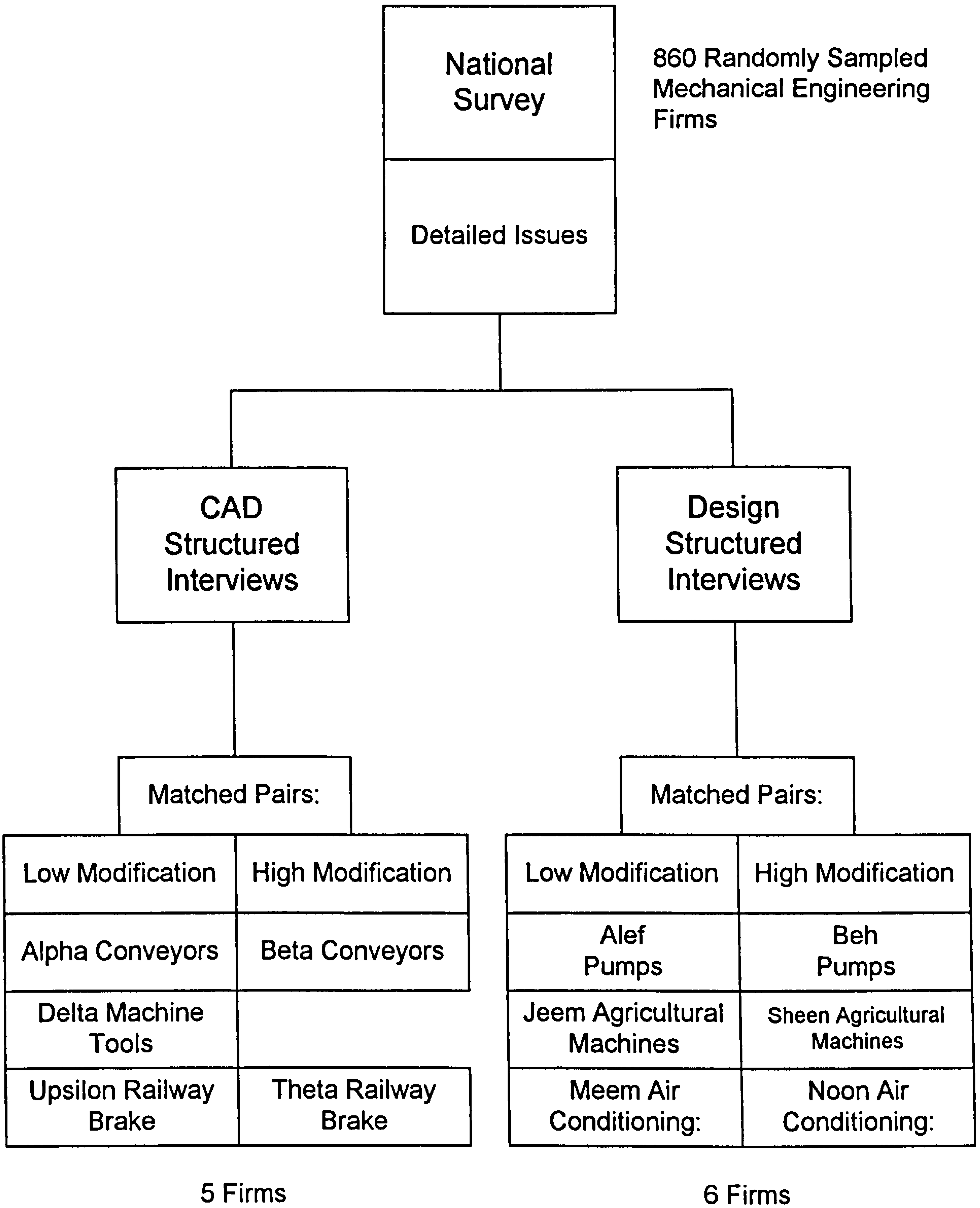
The first aim of the research was to provide a picture of the design - production interface and the management of product design in the UK mechanical engineering industry. This means that the methodology to be adopted must have a general focus. From a review of the literature it was seen that very few of the studies of the design process are concerned with the generality of the practice of design in industry as a whole (see Table 3-1). Rather, such studies, are based on in-depth structured interviews of individual firms, individual products or at best groups of individual products or companies. The studies mostly have small sample sizes. The only large sample sizes are limited to microelectronics use (Northcott & Walling 1988), medium and large size firms (Ingersoll Engineers 1989), Swedish large machinery and metal working (Trygg 1992), 13 sectors of UK manufacturing (Potter & Roy 1991) and self-selecting award winners (Ughanwa & Baker 1989). The samples contain miscellaneous products with no systematic basis for selecting the products. The samples also contain products of different industries, this limits the conclusions that can be drawn - the conclusions for one industry will not necessarily apply to another.

The information from most structured interviews while being in depth, is far too specific to the firms and products concerned. The implications gleaned therefrom, therefore, cannot easily be applied to all firms within an industry or all products within a firm or industry. Research so based has the major drawback that any implications and recommendations for the improvement of design performance within firms will have a) a narrow applicability only to those firms having similar characteristics to the researched ones and b) have indeterminate scope/ applicability for firms dissimilar to the researched firms. That is, it would not be known if the recommendations proposed applied to any particular firm which was dissimilar to the researched firms. This latter limitation seriously undermines the general-validity of research based upon case studies. Even studies which include a large number of case study firms, twenty in the case of Pawar (1985), cannot overcome this limitation.

The limitation of lack of generality can be overcome by a survey. This is the ideal research method to produce general conclusions, the scope of which can easily be ascertained. Thus, the second limitation of the applicability of results can also be overcome by a survey. It was for this reason that a questionnaire survey was adopted as a research instrument. It was decided to survey a whole industry to overcome the limitations of including more than one industry in the study. Also after preliminary investigations it was decided to survey the mechanical engineering industry. This was because it accounted for a large proportion of manufacturing industry and the impact of CAD would be less than the electronics industry. This explains the choice of a national random survey of the UK mechanical engineering industry. Such a systematic examination of the management of product design in the UK mechanical engineering industry has never been done before, and thus forms the first claim to originality of the work.

Although a survey can overcome the lack of generality and help the determination of the scope of the results it cannot provide the in-depth information and analysis of structured interviews. It was thus decided to undertake some follow-up structured interviews. However, the question remains as to how the results from these two differing methodologies can be combined. The answer was to use issues, determined to be significant from the survey, as a bridge into the structured interviews. These issues would be determined after the survey had been conducted in order to allow maximum flexibility in the methodology. This provides an evolutionary or developmental methodology. These issues were later identified as the design performance measures - modification and standardisation. Further, the use of CAD was found to merit further investigation. Thus two sets of follow-up structured interviews were devised. One set, consisting of five firms, investigated modification and standardisation for CAD user firms. A second set investigated modification and standardisation for design firms in general. This research design also helps to fulfil the second and third aims of the research. The second aim, to analyse the design - production relationship in terms of product design effectiveness, is fulfilled by the measuring of design performance, in the survey, and subsequent analysis of the survey and structured interviews. The fulfilment of the third aim, to develop guidelines for the better management of product design, was met from analysing the survey results and greatly aided by the detailed information provided by the structured interviews. This latter allows the actual guidelines to be spelt out rather than remaining at the level of general exhortation. The methodology of the two sets of structured interviews is reported below in sections 3.17 to 3.30.

Figure 3-1The Design-Production Interface: Study Methodology



3.3 The Research Design

The research design, illustrated in Figure 3-1, of both a national survey and a set of follow-up structured interviews is a novel methodology and forms one claim to originality of the research. It is better than either a survey or structured interview methodology - combining the best of both and overcoming the limitations of each. It has learnt the lessons of other studies' methodologies. Other researchers have not combined survey and structured interviews in this way. The only combined methodology is the postal questionnaire and interviews of Potter & Roy (1990). What their study lacks is the systematic structuring or linking of the two methodologies together. The combined survey - structured interview method put forward here compensates for the lack of information produced by a single methodology approach. It is thus the best methodology, adopted to date, for studying the design - production interface and the management of product design.

3.4 Survey Research Design

The design of the research reported here is intended to produce a snap shot of the design activity of mechanical engineering firms. From this picture will emerge information about the types of firms and their products, those who carry out design of products and those who do not. This will enable the proportion of mechanical engineering firms that perform design to be determined, and the implications for different firms and product types to be determined. Thus, the scope of guidelines that emerge from the research can be determined. This information can then be used in further research to investigate particular issues.

The research is intended to have a general as opposed to specific focus. For this reason it was decided to choose a questionnaire survey as the research instrument. The questionnaire would be sent to a random sample of UK mechanical engineering firms. This would ensure that the results of the survey would be representative of the UK mechanical engineering industry. It should be noted that this somewhat constrains the analysis and interpretation of the results of the survey. This is particularly the case with size of firm. The size of firm, in terms of employees, can be said to influence the amount of design activity the firm carries out. Thus, it can be hypothesised that larger firms will have formally constituted design departments, whereas smaller firms on the other hand would only employ individual or small numbers of designers. It would be interesting, from a research point of view, to compare the design performance of large and small firms. With a random sample this may not be possible because either there would not be enough large firms or not enough small firms responding to the survey to draw statistically valid conclusions. If a stratified sample, which included equal numbers of small and large firms, were used such a comparison would be possible. Hence, the objective of generality somewhat constrains the possible analyses and interpretation of the survey results.

3.5 Selection of Respondent

A further methodological difficulty has to be considered, that of the respondent to the survey. It is intended that the survey be a postal questionnaire which respondents within firms complete and return. The problem arises as to who is the most suitable respondent to send the questionnaire to? This is due to the research being concerned with the design and production functions within a company. Hence, it concerns two different functions within the firm. The first solution of sending two questionnaires, one to the design function and the other to the production function, was rejected. This is because two respondents for each firm would create problems in analysing the data. What, for instance, would happen if the two respondents gave conflicting responses to the same question? In some cases such conflicting responses would be useful - such as the respondents' opinion of CAD. In others - such as the number of designers employed by the firm - it would confound the analysis. It was thus decided to adopt the second solution of limiting the number of respondents to one per firm. The question then arises as to who should be this respondent? As mentioned above the research covers two functional areas within the firm and thus the ideal respondent would be one who spanned both functions. Such a respondent would be located at senior management level. This would be an engineering or technical manager, an engineering, design or technical director, and in some cases, particularly small firms, the managing director. The questionnaire was thus aimed at this managerial level.

3.6 Questionnaire Formulation

The process of formulating and refining the questionnaire was a lengthy one. First a list of issues pertinent to the research was drawn up. This was then transformed into a list of questions, resulting in 88 questions. This was too lengthy and thus a process of paring down the length was pursued. This eliminated issues which, while interesting, were not central to the research and secondly eliminated some questions which were designed to provide corroboration of the responses to other questions. Thirdly, when it was desired to measure a variable, such as modifications carried out to a product during design, a single question was used. This use of single indicators for variables has the disadvantage of constraining the reliability of the research. The process of refining the questionnaire resulted in a questionnaire some 50 questions in length. This was piloted on two groups of post graduate industrial engineering students attending courses at the then Polytechnic. This and further refinements produced a final questionnaire of 41 questions, with an estimated completion time of about an hour. The final questionnaire is attached as appendix B.

3.6.1 Questionnaire Wording

Each of the questions included in the questionnaire was subjected to close scrutiny in order to ensure that the wording had only one interpretation. Ambiguous wording was eliminated and clarification added in some cases. Questions which sought the opinion of respondents were avoided, rather factual questions to which a ready, and potentially verifiable, answer could be provided were posed. The final questionnaire was desk top published to give it a professional finish and to provide an eye catching and interesting design, to encourage people to fill it in.

3.7 Source of Addresses

The addresses for the survey were obtained from the FAME (Financial Analysis Made Easy) database. Other possible sources such as Chambers of Commerce, commercial directories, engineering institutions, the Engineering Industry Training Board were rejected on the following grounds. Chambers of Commerce and industry associations, and similar organisations where a fee is paid for membership, can be said to provide self-selecting firms. That is, firms which can be said to be paying better attention to management and running of the company than firms who are not members. A similar argument applies to firms who are members of engineering institutes. The EITB were also rejected for similar reasons, and also the fact that many firms avoid the statutory obligation to be members. With commercial directories the exact nature of their coverage of mechanical engineering could not be established. (Many firms pay for inclusion, there may be a geographical bias to inclusion and the numbers of firms included is not known nor their representativeness of UK mechanical engineering). Finally, there is the consideration of convenience - FAME is computer accessible and the other sources are not. This is a serious problem in the case of printed commercial directories where the time required to manually compile a random sample frame would inordinately extend the time taken to complete the research. There are other computer databases but these were rejected on grounds of lack of full coverage of firms in the industry (only possessing quoted companies) and also cost. The choice of source database was narrowed down to two: FAME and British Telecom's Yellow Pages database. Both are computer accessible but differ greatly in cost. FAME is free, but Yellow Pages would have cost £400 for a minimum 4,000 addresses. This latter amount was outside the budget of the research, but also the number of small firms included would be large. This would produce a sample frame which was biased toward small firms (including "one-man and a garage" operations). Thus it was decided to choose the FAME database.

The FAME database is a database of UK industry compiled from Companies' House by Jordans of London. The database holds the major public and private companies (quoted and unquoted) operating in the UK. Various criteria were used by Jordans in selecting the firms to include in the database. Major UK firms were included, as were companies specifically requested by Jordans' clients. The total number of firms in the database was 140,000 of which full records are held for 70,000. The database is held in computer accessible form (CD-ROM) and this is a major advantage when selecting firms. Information held on firms is extensive covering name, address, phone number, full profit and loss and balance sheets and trading addresses. The database also included names and home addresses of the firms' directors. This information was used in mailing the questionnaire, see below. Firms are also classified, by Jordans, into their standard industrial classification (SIC). This criterion was used to select the mechanical engineering firms.

3.8 Sample Frame

There are 10,606 mechanical engineering firms held in the FAME database. In order to provide a random sample of UK firms a sample size of 120 to 180 firms is necessary. Note that the representativeness of a sample is not linearly dependent upon sample size, statistical limits are reached around the 150 mark. Including extra firms above this will not improve the representativeness of the sample (See Fowler, 1988). Thus, assuming a required sample size of 200 and a conservative response rate of 20% gives a sampling frame of 1,000. This sampling frame was selected from the database by choosing firms on which the most recent financial information was available. Thus ensuring up to date addresses and currently trading firms were included. This consisted of 1,971 firms. The required 1,000 were chosen by selecting every other firm from a random starting point of 2 and a second random sampling of the remaining firms.

3.9 Selection of Firms

The selection of firms and respondents followed the following algorithm. Firstly, a check was made to eliminate non-mechanical engineering firms from inclusion. Sometimes this was done using the name of the firm and in more ambiguous cases by examining the other directorships of the directors. An example of the former, Central Motor Auctions Ltd - clearly an auction firm, was eliminated. Of the latter, Wessex Refrigeration, was included as the other directorships (of Wessex Pumps) showed the firm was a refrigeration plant manufacturer as opposed to a cold storage warehouse. This process produced the 860 firms to whom the questionnaire was mailed.

3.10 Determination of Sendee / Recipient

Where possible the questionnaire was mailed to a named individual, at the firm's registered office, as follows. The source database only included named directors and thus these had to form the basis of the names to be mailed to. No information about departmental managers or other job titles was given in the database. It was hoped to mail to technical directors but not a single technical director was listed. Hence, managing directors were chosen above other directors. Second, chairmen who lived in the vicinity of the firm were chosen. Those who lived far away were replaced with other directors who lived near the firm, or if none were listed to the "managing director". Thirdly, directors who held directorships in engineering firms as opposed to service industry firms were chosen, again the qualification of place of abode was applied. Lastly, if no directors were listed the questionnaire was sent to the "managing director", with no name attached.

3.11 Limitations of Questionnaires

The limitations of questionnaires as a research instrument are several. First, respondents may give the answers they think should be the answer rather than the actual one. This is particularly the case as regards the question on the number of modifications made to a product, which attempts to give an indication of design performance. Respondents could very easily be motivated to give a lower answer than the real one in order to enhance the impression of their firm. Due to the constraint of the questionnaire length no corroborating questions were asked. This limitation would also apply to interviews, but less strenuously. Although such false reporting may average out over the total number of responses and thus not be statistically significant. Another approach to prevent false reporting is to follow up firms, either on the telephone, or in person. Several persons within the firm could be approached and asked the same question and a consensus arrived at. Time and cost, however, given the size of the sample rule out such an approach.

A second limitation is that the questionnaire seeks to characterise a <u>firm</u> and not its products. This is an important point because not every product a firm launches is successful. Thus characterising a firm which uses matrix organisation for the introduction of its products as having a good performance may be false. This is because, although, the firm uses matrix organisation for most of its products the majority of its <u>successful</u> products are organised by, say simultaneous engineering. Hence, an incorrect inference could be drawn from the research, in that matrix organisation was judged as being for good performance, whereas in fact simultaneous engineering was. This limitation could only be overcome if a firm were intensively studied, such as in the case study method. Similar considerations apply to the process technology used to manufacture products. Again, characterising firms with mass process technology as good performers could be due to the products produced with batch or one-off process technology. Note also that good performance has been taken as an example to illustrate the issue of the limitations of questionnaires and confounding of the analysis and interpretation of results. The limitation and confounding applies to the other variables the questionnaire attempts to measure.

A more general limitation of the research design is the lack of triangulation. The research relies upon one research method - a self administered questionnaire. There is no attempt to confirm the results of the application of one method with another. Such an attempt, known as triangulation, would entail each selected firm being subjected to the application of two, or more, research methods/ instruments. This could take the form of a self administered questionnaire followed up by a personal interview. Once again the number of such interviews required (200) and the time and cost therein involved ruled out the approach.

3.11.1 Performance Measurement

A further methodological constraint applies to the measurement of performance. In order to measure performance, which connotes an improvement, one of two conditions must be fulfilled: 1) a period of time over which the improvement occurs must elapse or 2) some change must occur, after which an improvement is said to have occurred. In either of these two cases the classic research method is that of quasi-experimentation where two applications of the research instrument are carried out. One application is carried out at the beginning of the time period, or preceding the change, and a second at the end of the period, or after the change. Once again it is not possible to make two applications of the research instrument. Time and cost preclude this, but so too does the research design. Consider which change within a firm should be studied, the introduction of a new product? If so, which one? Which product that the firm has introduced best represents the average performance of the firm? This is a complicated enough question to answer for an individual firm but for a sample of companies is impossible. Thus measures of performance are confined to static measures, which relate not to the absolute performance of a firm, but to a comparative performance of the firm vis-a-vis other firms in the sample. This implies that drawing conclusions from the analysis requires some caution. Nevertheless, the research design put forward above is the best one devised to date, it is structured (survey and structured interviews - with linking issues), it is of an industry by random selection, it contains performance measurement and systematic comparison of performance and is therefore a rigorous methodology.

3.12 Questionnaire Analysis Method

The analysis of returned questionnaires will be performed by computer. The questionnaire was designed with this in mind. Questions were formulated in order to ease analysis by computer. The analysis will mostly consist of descriptive frequencies, such as how many firms design their own products, use design consultants etc. Some questions asked for the answers to be ranked, these enable statements such as "the most important achieved benefit of CAD was X" to be made. Comparative analyses of firms will be carried out in order, for example, to determine which method of organising for design gave the best performance.

3.13 Responses & Response Rate

The mailing of the questionnaire followed a two stage process. An initial mailing of 168 was sent out in order to determine an estimate for the response rate to the main survey. This produced a response rate of 12.5% which was considered low but adequate. The eventual sample size was 860 firms. The number of questionnaires received was 113, regarded as reasonable for statistical analysis purposes. This gave a response rate of 13%. The same response rate was achieved by Burcher (1992) in a 1990 survey of 2,700 manufacturing companies' capacity planning. The survey by Galliers et al (1993) of *Times 1000* British executives' critical IT issues had 125 responses, again a similar response rate of 12.5%. Ettlie & Warner (1992) had a sample of 43 firms with a response rate of 35%. Trygg's (1992) survey of Swedish large machinery and metal working companies had 162 with a response rate of 67%. The high response being due to only contacting relevant and large companies (more than 500 employees). Black & Baker's (1987) interview survey attained a 44% response rate, presumably due to the use of the interview method - phoning people up and making appointments. Thus, the sample size and response rate for this survey compare favourable with other contemporary surveys. The one advantage that the survey has is its tight definition - based on one industry, the others containing miscellaneous products and industries with no attempt to structure them.

Respondents to the survey were primarily top management, see Figure 3-2. Managing directors being the most frequent respondents. Analysis of the reasons for negative response to the questionnaire is shown in Figure 3-3. This revealed that the two most important reasons for negative response were firms not being mechanical engineering, or manufacturing, and firms being sales, or distribution, companies. The next most frequent reason was that firms did not design the products they manufactured. Thus, the reasons for negative, or non-response, were due to the inapplicability of the questionnaire to the firm mailed. Negative, non-response, was not due to faults in the research design or survey methodology.

3.14 Sample Bias Test

To verify the validity of the survey methodology a further test - a sample bias test - was carried out. The purpose of this test was to determine whether there was any bias in the responding firms. It would test whether the respondent sample was representative of the sample frame (ie. the mechanical engineering industry). For example, the survey topic was product design and it could be that only firms who design their products responded to the survey, and that the none designing firms did not. This would skewer, or bias, the sample away from being representative, making it only representative of firms who design products, rather than the industry as a whole. The survey would thus be self-selecting. The test procedure was to telephone 20 non-responding firms, selected at random from the sample frame. If the majority of these were not mechanical engineering firms then the survey is self-selecting, ie. biased. If an even number of these firms were not mechanical engineering or did not design products then the survey is representative. The results of the bias test were that seven firms were mechanical engineering firms that designed and manufactured products, meaning that the survey is representative of such firms. Six firms were non-mechanical engineering. Hence, the survey is representative of the mechanical engineering industry.

Fig 3-2: Respondents to Survey

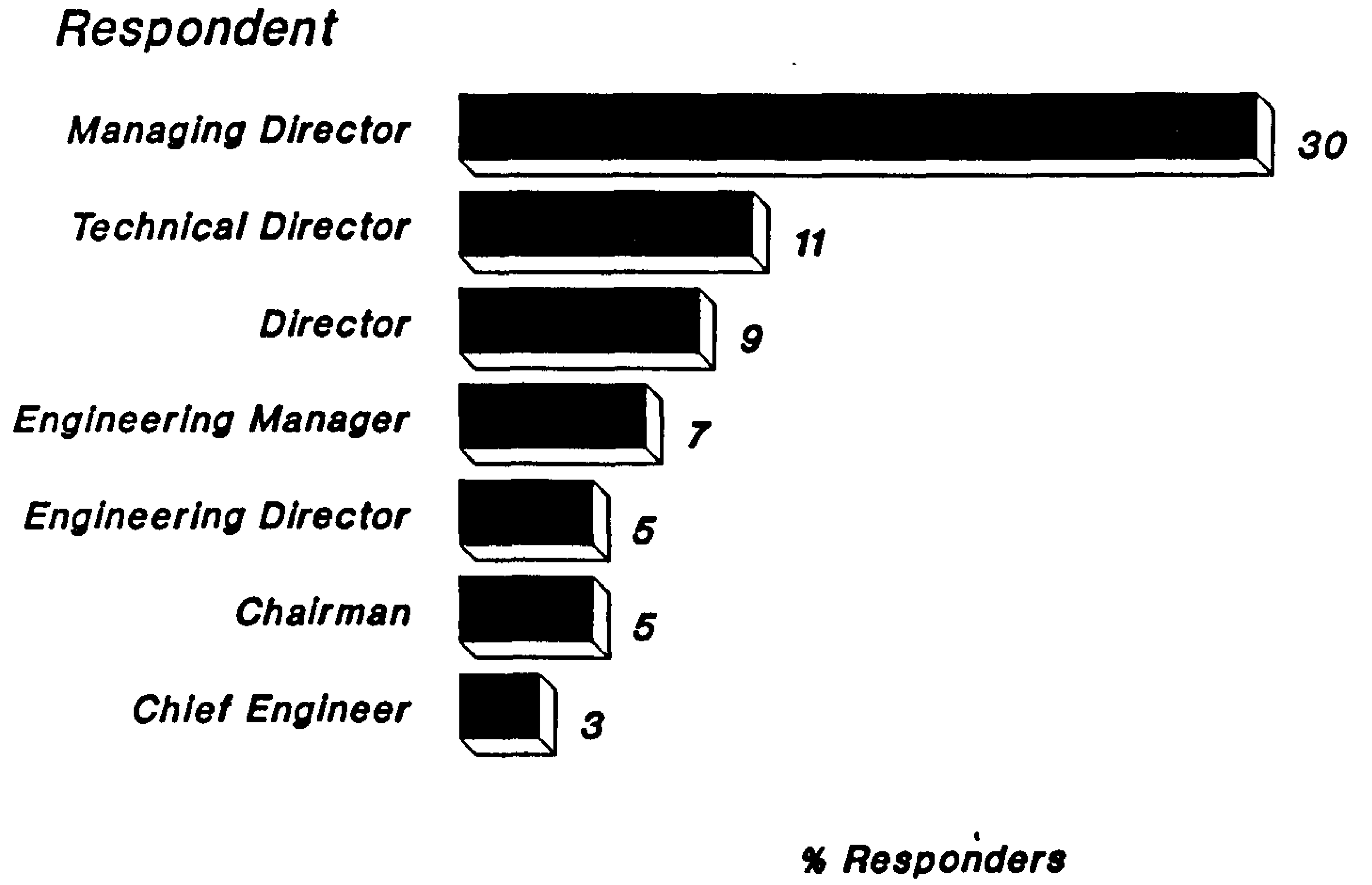
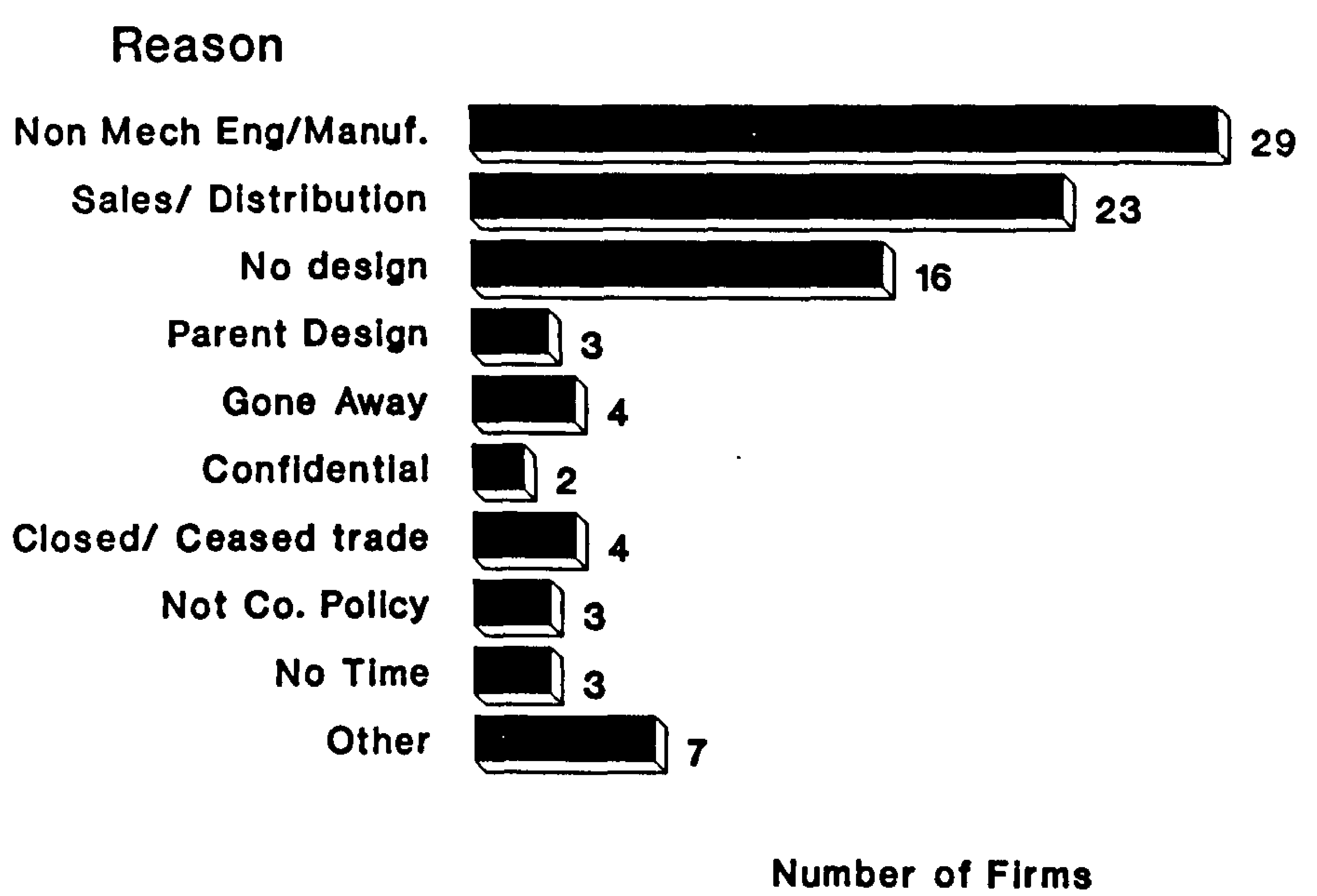


Fig 3-3: Reasons for Negative Replies



94 Firms

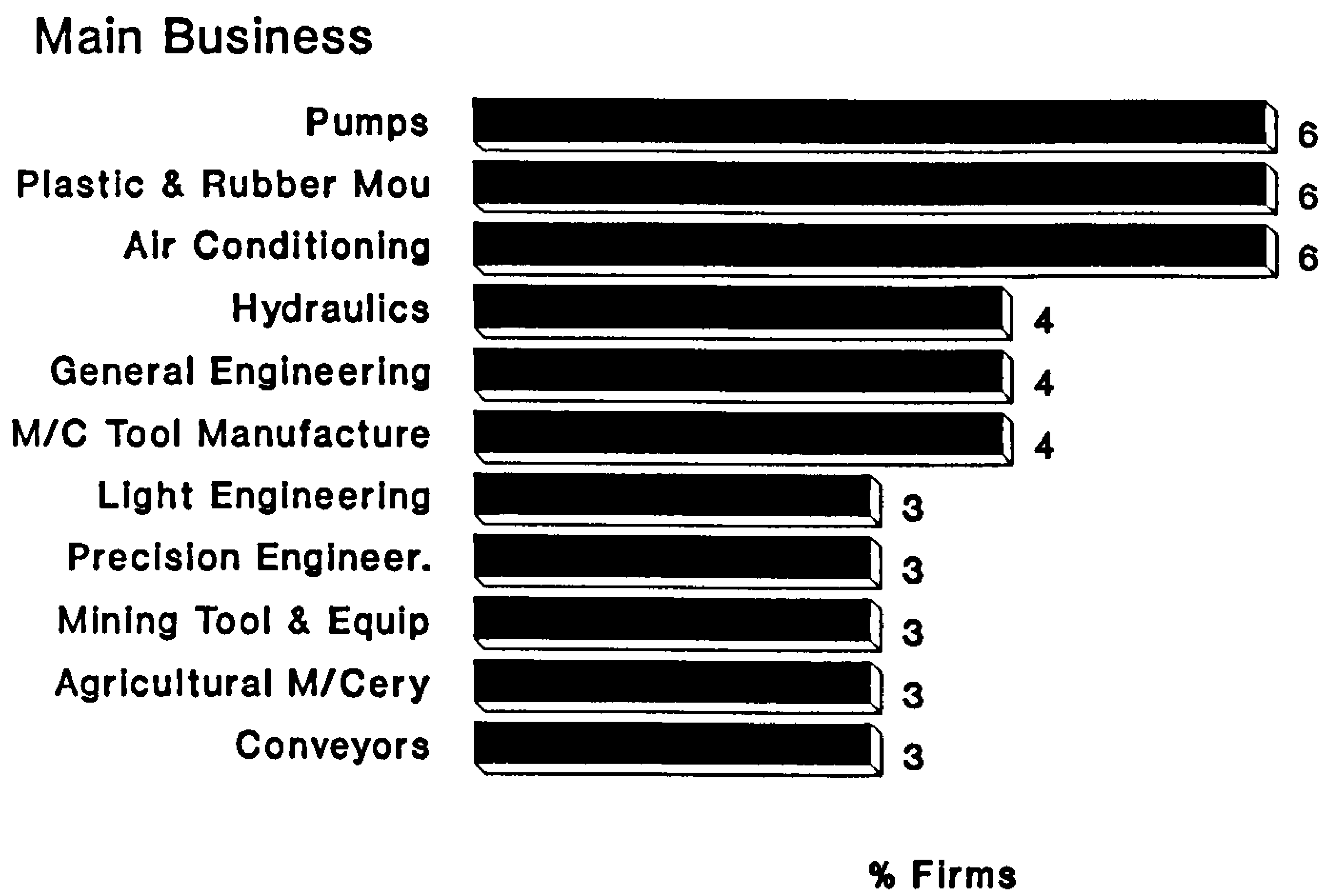
3.15 Characterisation of Survey Respondent Firms

The analysis of the nature of the main business of the responding companies is shown in Figure 3-4. These all fall into the classification of mechanical engineering. The analysis of products that were manufactured by firms is shown in Figure 3-5. The dominance of pumps as a product of firms can be clearly seen. Nevertheless, a good cross section of mechanical engineering is represented. The regional distribution of respondent firms is shown in Figure 3-6. This shows a bias towards the South East (32%) and West Midlands (15%). This is what would be expected for the national distribution of the mechanical engineering industry. Figure 3-7 shows the analysis of establishment employees of responding firms. The survey achieved a good coverage in the range 20 to 499 employees. A reasonable response from very small firms (less than 20 employees) was also obtained. Large firms, however, were under-represented in the survey. This reflects their under-representation in the industry as a whole. The analysis of sales turnover is shown in Figure 3-8. A reasonable distribution of firms over the size ranges of under £1 million pounds up to £10 million pounds was achieved. Ten to £30 million pound sized firms had a small representation of 10% each. Firms with more than £30 million pounds turnover accounted for only 7% of responding firms. Finally, Figure 3-9 shows the analysis of process technology of respondent firms. The majority of firms were, as expected, batch manufacturers. A third were one-off producers and only 6% were mass producers.

3.16 Survey Methodology Conclusion

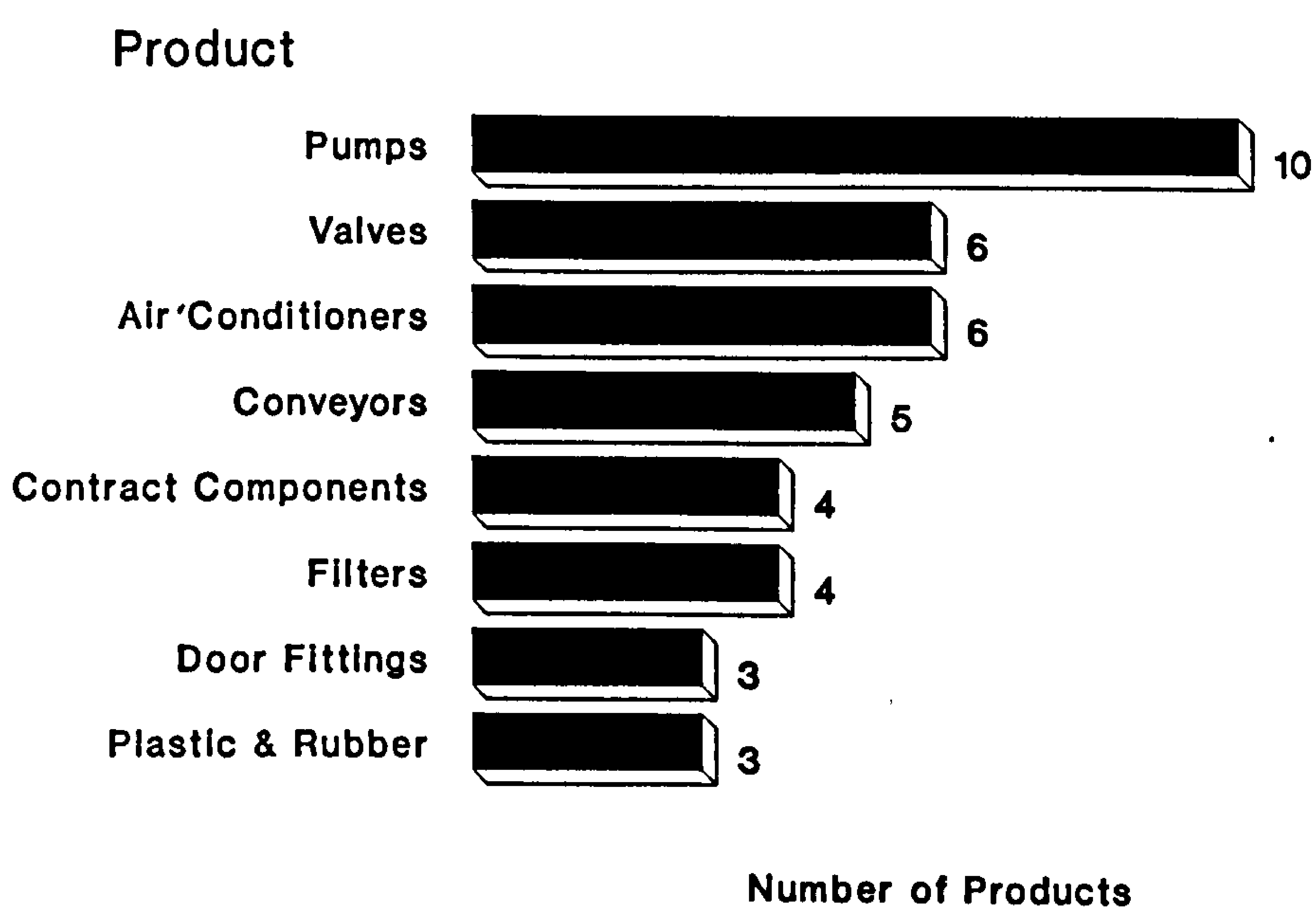
It can be concluded that the survey has produced a sound empirical base upon which to make generalisations about the mechanical engineering industry. A wide range of products, establishment employee size, region and turnover was achieved. Negative responses were due to the inapplicability of the questionnaire and not to faults in the research design or survey methodology. This concludes the discussion of the survey methodology. The next section presents the methodology of the structured interviews.

Fig 3-4: Nature of Main Business



Accounts for 44% of responding firms

Fig 3-5: Most Frequent Products



All other products occured twice or once

Fig 3-6: Regional Distribution

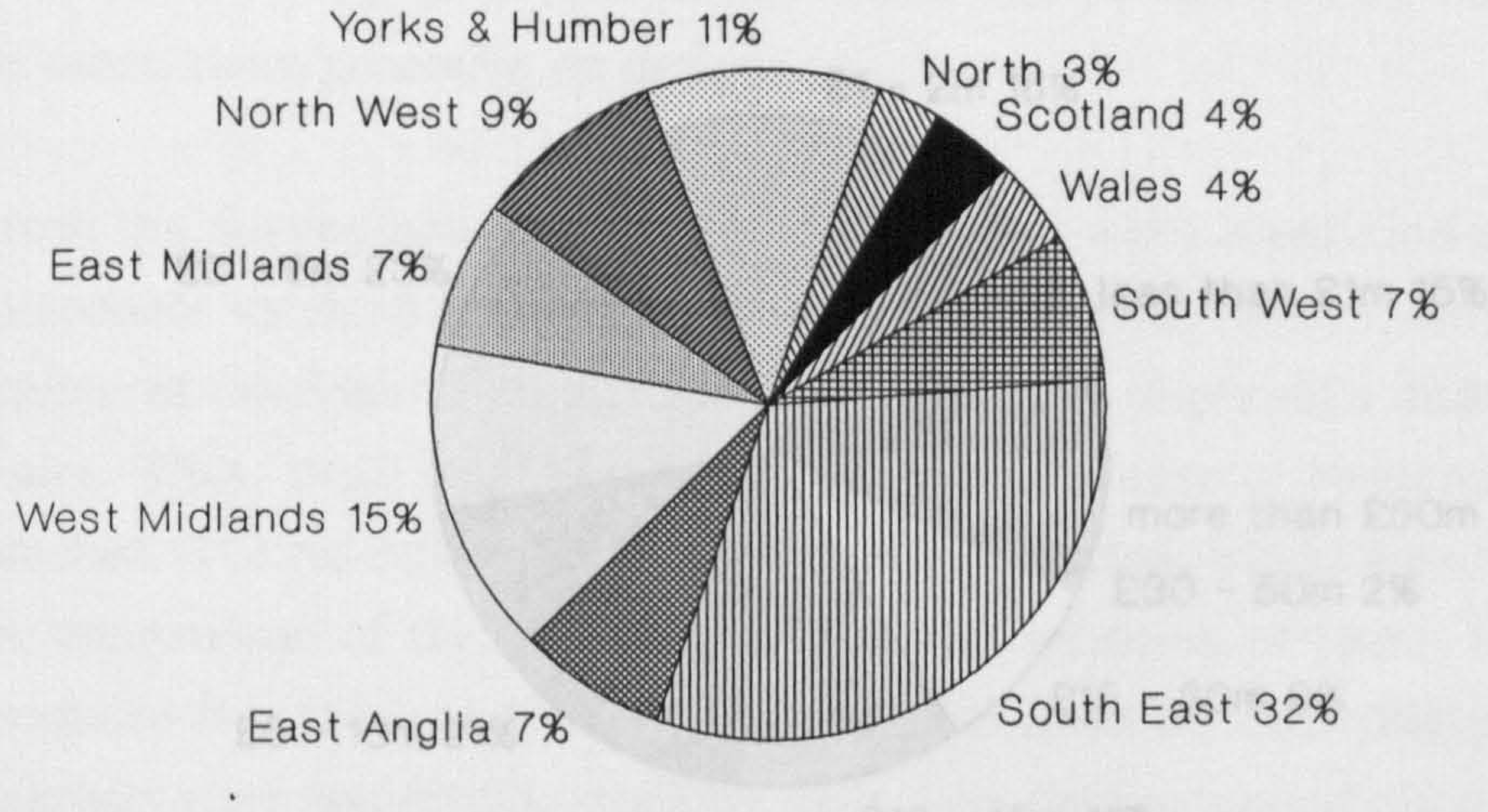


Fig 3-7: Establishment Employee Size

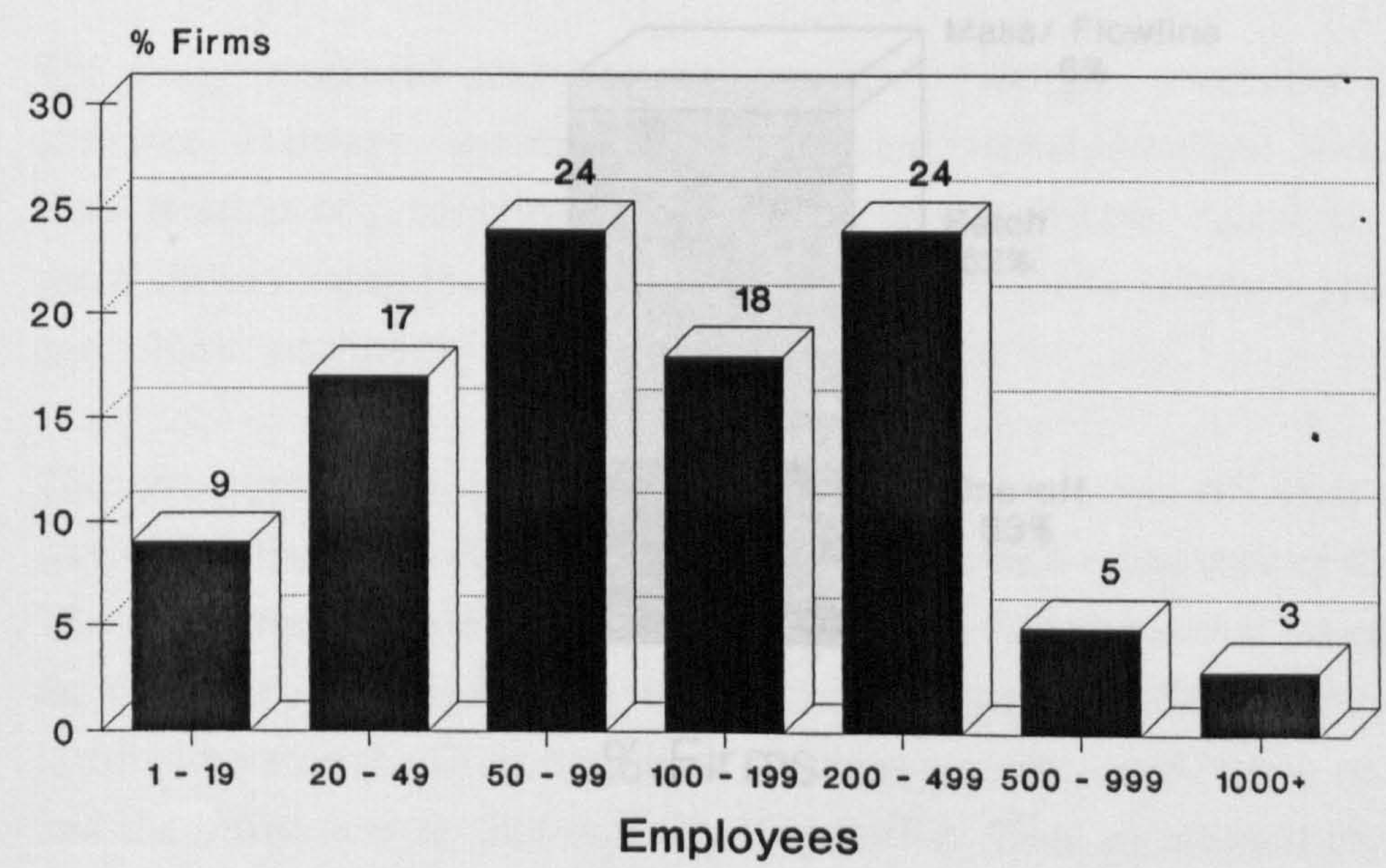


Fig 3-8: Sales Turnover (£ Millions)

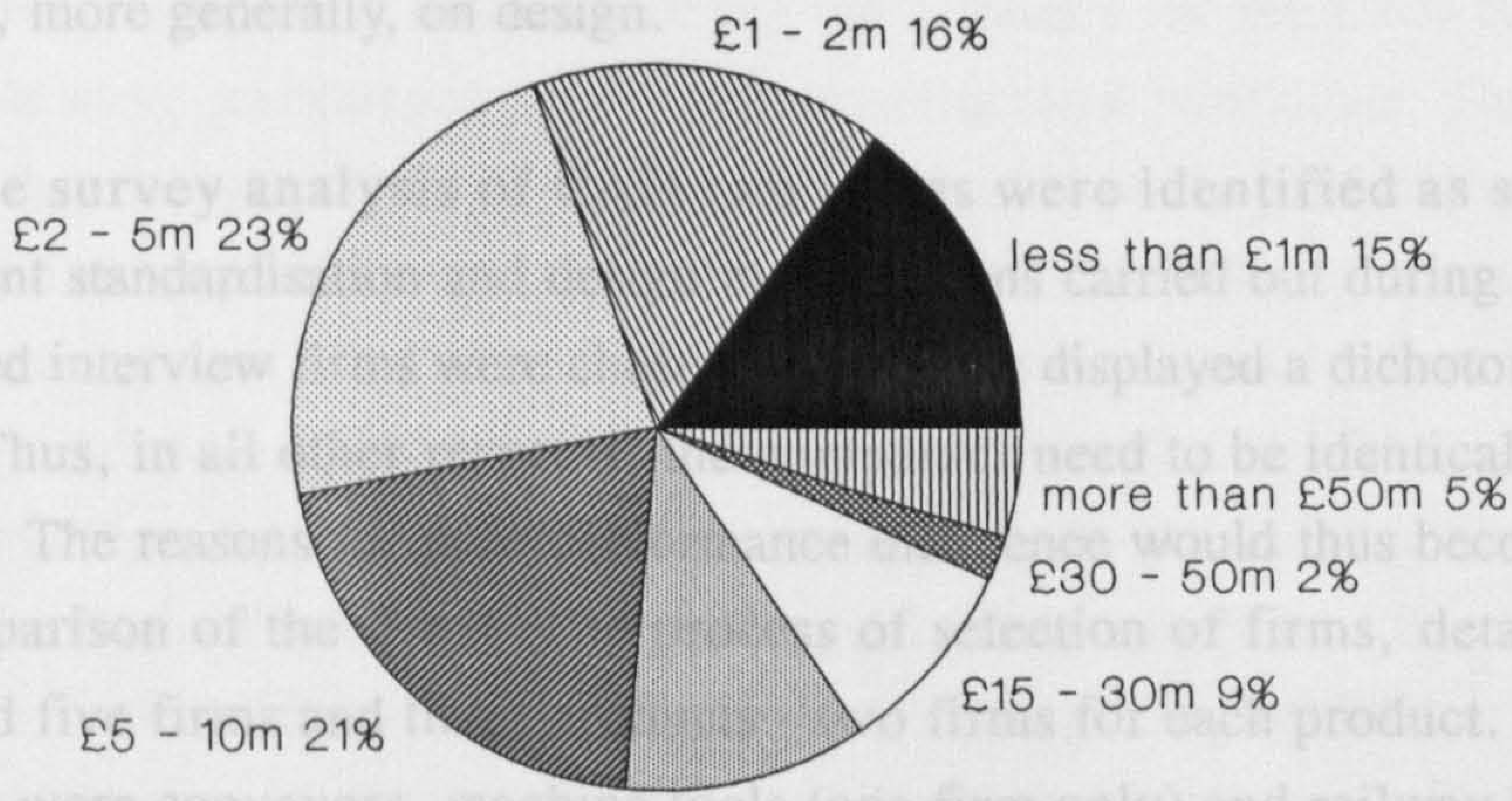
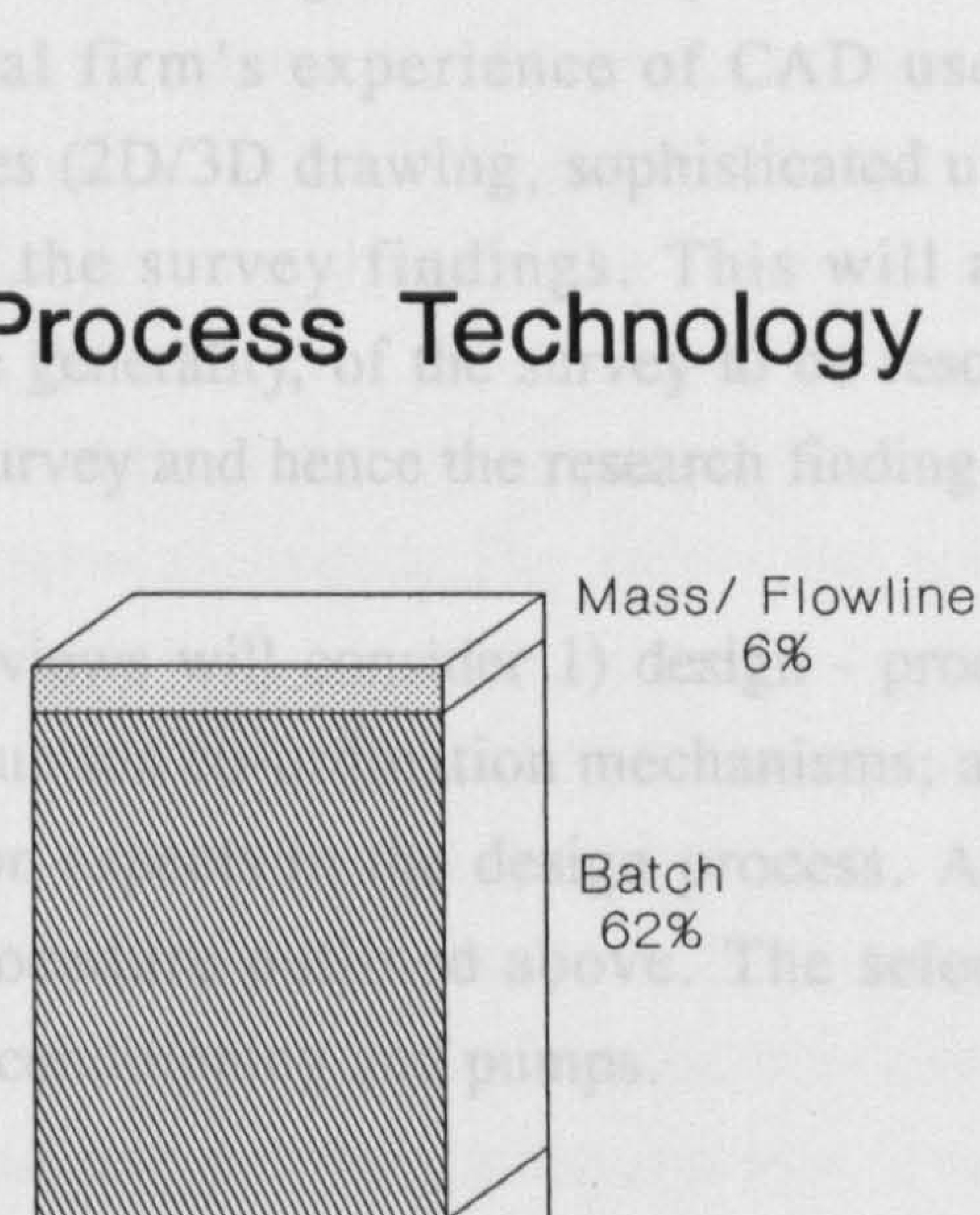


Fig 3-9: Process Technology



3.17 Structured Interview Methodology

This section describes the methodology adopted for the structured interviews. The structured interviews will centre around issues which were identified as significant from the analysis of the survey. Data gathered from the structured interviews will also be fed back into the analysis of the survey. This novel interaction between the survey and structured interviews forms a further claim to originality of the research. Two sets of structured interviews will be carried out, one on CAD and the other, more generally, on design.

From the survey analysis of CAD two issues were identified as significant: component standardisation and design modifications carried out during production. Structured interview firms were chosen so that they displayed a dichotomy on these issues. Thus, in all other respects, the companies need to be identical, or closely matched. The reasons for their performance difference would thus become clear in the comparison of the firms. The process of selection of firms, detailed below, produced five firms and three products - two firms for each product. The chosen products were conveyors, machine tools (one firm only) and railway brakes. The structured interviews would also gather in-depth data about CAD use by considering the individual firm's experience of CAD use. Also the firm's experience on certain issues (2D/3D drawing, sophisticated uses of CAD) can be contrasted with some of the survey findings. This will allow some of the ambiguity, arising from the generality, of the survey to be resolved. It would thus bolster the validity of the survey and hence the research findings.

The design structured interviews will consider 1) design - production organisation structure; 2) design - production co-ordination mechanisms; and 3) early and late consideration of production aspects in the design process. Again six companies were chosen using the procedure outlined above. The selected products were agricultural machinery, air conditioning and pumps.

The structured interviews themselves will involve a one-off visit to the firm concerned. Each will thus form a snap shot of the firm at the date of the interview. The structured interviews will not take the form of longitudinal investigations of the firms' experiences but only capture the perceptions of the interviewee. This is justified because the firms have been previously chosen as differing on some issue and the purpose is to find out why they differ. Thus an attempt to produce an account of how each firm came to differ (ie. a history) from the others will not be produced - such would require interviews over many months. Also the usual format of structured interviews of product design - that of tracking the experience of single or multiple firms' introduction of a new product will not be done (See the case studies of Oakley 1978 and Pawar 1985). Interviews will thus revolve around the issues of difference and any other issues which emerge during them as being of interest or significant.

The interviews for CAD were carried out over the period October 1990 to February 1991. The design interviews were carried out over the period January 1991 to June 1991. The selection of the interviewees for the CAD cases studies was a little more problematic than the design structured interviews. The reason for this was that the questionnaire respondent was not usually in charge of the CAD system. Thus, organisation charts, where included, and telephone inquiries were used to track down a suitable interviewee. This was usually the CAD system manager or design manager who had responsibility for the CAD system. The interviews themselves were interviews with single individuals. They lasted between an hour and a half and two and a half hours. They consisted of a face-to-face interview followed up by a factory tour - lasting roughly half an hour. The interviews were semi-structured, although a separate interview schedule was not used, the respondent's questionnaire was used as an interview schedule. The questionnaire was thus used as a prompt for the posing of open ended questions to get the interviewee to elaborate at will. Thus qualitative data was collected, with the interview following the conversation of the interviewee listening out for interesting experiences. An eye was kept continually on the research issues which the interviewee had not discussed, and at the opportune moment a question asked. The interviews were not taped recorded. The author has found in his previous research that this is counter-productive, as the transcription of the tapes is inordinately time consuming. Thus, again based on the author's experience, extensive notes were taken during the interview. Secondly, the structured interviews were written up immediately they were carried out. This ensured that important background information, which it would be impossible to record on site, was written down and could thus be used in the analysis. The firms visited were not concentrated in any one geographical location. Five firms were located in industrial cities the rest in rural locations. The surprise was that no firms were in London and only one in the West Midlands.

3.18 Issues to Investigate

The research design intended that structured interviews of significant issues would be undertaken in order to complement the survey results. The structured interviews would provide depth to the survey's generality. It was intended that they should also clarify issues which were determined to be significant. It is these significant issues which act as a bridge between the two methodologies. After the preliminary analysis of the survey responses relating to CAD had been completed two significant issues arose as being worthy of further investigation. First, it was apparent that CAD user firms tended to have higher modification than non-CAD user firms, and CAD users were using the CAD system during production. Thus, the question arose as to whether this was because firms with CAD were having to modify designs during production - arising from the use of CAD, or were firms able to respond more easily to market and customer needs - through the use of CAD? The data on the survey questionnaire was not sufficient to clarify this issue and so it was decided to undertake structured interviews to investigate the modification phenomenon. The second issue identified in like manner was that of standardisation. The structured interviews were structured in an open ended manner, in that significant or interesting issues which arose from the experience of each individual firm were probed and included in the subsequent write-up and analysis. It was decided to use the issues of modification and standardisation to structure the design structured interviews as well.

3.19 Pros and Cons of the Structured Interview Method

The pros of the structured interviews were the following. Excellent co-operation from the interviewees was obtained in all cases, even managing directors personally conducted the author around the factory. Everyone was keen to answer the questions asked and did not prevaricate or refuse to discuss certain topics. The benefits of this type of short interview are several. First, two interviews can be carried out on the same day - this was done twice. Second, it was very easy to gain access to the companies - they were not being asked for their long term co-operation (which companies are increasingly reluctant to give in the current period of recession). Third, they were both quick and simple to write up. The quickness of the interviews was helpful to the interviewees as it prevented them from getting bored or tired - and thus maintained their full attention and co-operation. Fourth, they were very efficient in getting the research questions asked quickly and with a low level of effort. Fifth, due to their short duration, many more structured interviews could be carried out - eleven were done, whereas, at the beginning of the research, it was anticipated to only do three to six structured interviews. Sixth, the larger number allowed more in-depth qualitative data to be collected from more firms. Seventh, more firms allowed more analysis and comparison to be carried out - not only on the significant issues but also across product and size.

The disadvantages of the adopted structured interview methodology can be said to be: First, the single chance in the interview to obtain answers to the research questions. This was counter-balanced by the opportunity to telephone the interviewees after the visit. Second, the short duration which meant not enough time was available to ask all the interesting questions (this was compounded by the single visit). This problem occurred in two interviews. Third, lack of corroboration of the data gathered. This occurred as only a single interviewee was consulted. In longitudinal case studies many people can be asked the same question, information can thus be checked, or in the case of differences of opinion the reasons for it established. Fourth, the single respondent meant that the data gathered, and thus the interpretation and analysis, relied upon the perspective of one person who may, due to their location, as design manager, give different answers to say, the production manager. A departmental perspective may be obtained rather than a company perspective. Also the lack of senior position of the interviewee limited their knowledge of the company's operations. This was more of a potential problem with the CAD structured interviews, although, it did not materially affect the cases. Fifth, the single interviewee may be limited in their knowledge and experience of the company - ie. being recent appointees or not having access to information which the production department had. The former was not the case with the interviewees, but the latter was certainly a potential problem, although, it emerged on only two to three occasions.

The structured interviews were also written up in a consistent manner. This allows the reader to carry out their own comparison and check the interpretations of the author. The cases can also be read as a whole. Further, each case was written so that it stood on its own. Each can be read independently and can be used for other purposes - teaching, further research etc. As a final note the cases are written up using the vocabulary of the respective interviewees. This was done to a) to provide interesting reading and b) to ensure that the understanding of the interviewee was presented with as little interpretation of the author as possible. The two next sections deal with the selection of the firms for the CAD and design structured interviews.

3.20 Selection of CAD Structured Interview Firms

Selection of the structured interview firms proceeded as follows. First, CAD user companies with high and low modification were collected together. Then the products these companies made were collated. Where products with only one company manufacturing them existed they were placed on one side. The remaining product companies were then sorted into high and low modification firms. The high and low modification firms were then compared on company, establishment size and turnover to produce as near a matching pair as possible. This process produced the three products of conveyors, machine tools and railway brakes. Fortunately, reasonable size matches were possible. The next section describes the selected structured interview firms.

3.21 Conveyors

The first of the products to be selected was conveyors, or mechanical handling. These are devices for conveying goods from one location to another. They consist of a conveyor layout or support system and the conveyor technology - rollers, chains etc. Also required are traction devices, motors or other, and control equipment. They are relatively simple devices with straight forward manufacturing requirements. Table 3-2 below compares the two firms selected as the conveyor structured interview firms.

	Alpha	Beta
Employees:		
Establishment	45	40
Company	45	40
Turnover (£m)	2.5	2
Modification	0-10%	21-30%
Standardisation	61-80%	61-80%

<u>**Table 3-2: The Conveyor CAD Structured Interview Companies**</u>

The interviewees were; Alpha: Design office manager (previously the drawing office manager, the questionnaire respondent); Beta: CAD systems manager (a sub-ordinate of the questionnaire respondent and also a member of the family that owned the firm).

3.22 Machine Tools

Machine tools are fairly complicated pieces of equipment both mechanically and now, with computer control, electronically. It was quite a surprise to find so many machine tool manufactures, four, replying to the questionnaire and, therefore, suitable for case studies. Unfortunately, however, it was not possible to obtain a suitable match between two similar firms. This was because the first choice, Delta, was a medium sized firm manufacturing a wide range of machine tools, and the second choice a similar firm (the closest match) only used CAD for electrical work. A third choice was precluded due to two reasons. First, the chosen firm were extremely reluctant to allow an interview, many months of persuasion failed to convince them. The second reason was that the remaining two firms only manufactured a simple range of machine tools, ie. gear hobbing etc. machines, hence they could not usefully be compared with a manufacturer of a wide range of machine tools. It was hence decided to leave these firms out of the comparison, resulting in only one machine tool company being included in the structured interviews. Delta was also the firm with low modification. Table 3-3 below shows the details of the machine tool manufacturer selected as the structured interview firm.

	Delta
Employees:	
Establishment	540
Company	9000
Turnover (£m)	25.5
Modification	0-10%
Standardisation	81-100%

Table 3-3: The Machine Tool CAD Structured Interview Company

The interviewee was the Engineering office manager (two below the managing director, but not the questionnaire respondent).

3.23 Railway Brakes

Again railway braking systems are fairly standard and well known devices. They consist of the brakes themselves - discs or callipers - and the pneumatic control system etc. These functional systems have to be fitted into the space allocation on the trains they will be fitted to. This involves much design tinkering for each system. Table 3-4 below compares the two firms selected as the railway brake structured interview firms.

	Theta	Upsilon
Employees:		
Establishment	650	220
Company	1300	260
Turnover (£m)	31	20
Modification	51-70%	0-10%
Standardisation	21-40%	61-80%

Table 3-4: The Railway Brake CAD Structured Interview Companies

The interviewees were; Theta: CAD/CAM systems manager (also with responsibility for half of the work of the design office, a sub-ordinate of the questionnaire respondent); Upsilon: CAD supervisor. This person had some responsibility for the drafters as well. Neither of the interviewees was the questionnaire respondent.

3.24 CAD Structured Interview Selection Discussion

This section discusses the goodness of match obtained. The selection of firms produced two pairs of firms which differed on their modification performance. It was not possible to produce such a clear dichotomy for standardisation. Alpha and Beta Conveyors were good matches on size and on product. Delta Machine Tools stands on its own, but it can be compared with Theta Railway Brake on size. However, Upsilon was approximately a third of the size of Theta and thus the comparison will not be clear cut. Product match for railway brakes was excellent. Despite the one missing firm the overall basis for comparison is very good. The rigour of the methodology will provide an excellent basis for comparative analysis to determine the critical factors determining the difference in performance and behaviour of the firms.

3.25 Selection of Design Structured Interview Firms

Selection of the design structured interview firms proceeded as follows. First, companies with the same product were collated. Companies which had already participated in CAD structured interviews were eliminated. From the resulting list those with high and low modification were collected together. The high and low modification firms were then compared on company establishment size and turnover to produce as near match as possible. This process produced the three products of pumps (a simple product), agricultural machinery and air conditioning equipment (both complex products). This would also allow the comparison of simple products with more complex ones. Fortunately, reasonable size matches were possible. The next section describes the selected structured interview firms. The names for the structured interview firms have been chosen from the names of the Persian alphabet - in contradistinction to the Greek alphabet for the CAD firms. The pronunciation of the names is as in English: Alef, Beh, Jeem, Sheen, Meem and Noon.

3.26 Pumps

The first product was a simple one - fluid pumps. Table 3-5 below compares the two firms selected as the pump structured interview firms. Unfortunately, it was not possible to produce a match of similar pump manufacturers. This was due to the unsuitability of the firms, either a match on size could be produced, as with

Alef and Beh, or else only a weak match on product could be produced. For logistical reasons of the research (the location of the firms) it was decided to choose the size match. Alef is the better firm on two measures - standardisation and consideration given to production. The abbreviations used in the table have the following meaning: D-P organisation describes which type of organisational structure the firms had for design and production functions. Similarly D-P Co-ordination describes the type of co-ordination mechanism the firms used. Prod Aspects shows when in the design process the firm considered production aspects.

The interviewees were; Alef: marketing manager (previously the engineering manager, the questionnaire respondent); Beh: technical director, also the questionnaire respondent.

	Alef	Beh
Employees:		
Establishment	100	116
Company	112	119
Turnover (£m)	5.54	6.1
Modification	0-10%	0-10%
Standardisation	61-80%	21-40%
D-P Organisation	IPPD	IPPD
D-P Co-ordination	Meetings	Meetings
Prod Aspects	eml	mL

Key: IPPD: Integrated Product-Process Design Department; eml: early, medium and late consideration of production aspects; mL: medium but mostly late consideration of production aspects.

Table 3-4: The Pumps Design Structured Interview Companies

3.27 Agricultural Machinery

Agricultural machinery was chosen due to its complex nature. It requires the use of drives (of various types), cutting blades etc., pumps or blowers etc. Table 3-6 below compares the two firms selected as the structured interview firms. Jeem were better in this case.

	Jeem	Sheen
Employees:		
Establishment	220	180
Company	220	
Turnover (£m)	14	8.5
Modification	0-10%	11-20%
Standardisation	21-40%	21-40%
D-P Organisation	Matrix	IPPD
D-P Co-ordination	Proj.Mngr	Proj.Team
Prod Aspects	e&L	M

Key: e&L: early but mostly late consideration of production aspects; M: (Medium) production aspects considered in the middle of the design process.

Table 3-6: The Agricultural Machinery Design Structured Interview Companies

The interviewees were; Jeem: design director (the questionnaire respondent); Sheen: managing director (again the questionnaire respondent).

3.28 Air Conditioning

Air conditioning equipment is also a complex product. Typically it involves the use of pumps, filters, fans and coolers all packaged in a sheet metal box. It was for this reason that it was chosen to carry out structured interviews on. Unfortunately, Noon did not manufacture the same product as Meem - this was discovered to late. Noon produced clean air (contamination free) environment cabinets and rooms as opposed to air conditioning machinery. It was decided to keep the comparison to see if interesting issues arose. Table 3-7 below compares the two firms selected as the structured interview firms.

	Meem	Noon
Employees:		
Establishment	499	70
Company	520	75
Turnover (£m)	27	5
Modification	11-20%	0-10%
Standardisation	61-80%	81-100%
D-P Organisation	IPPD	Matrix
D-P Co-ordination	Proj.Mngr	Proj.Team
Prod Aspects	e&M	Ml

Key: Proj.Mngr: Project Manager; e&M: early but mostly medium consideration to production aspects; Ml: mostly medium but some late consideration.

Table 3-7: Air Conditioning Design Structured Interview Companies

The interviewees were; Meem: engineering manager (15 minutes only) and a project engineer; Noon: technical director. None of these three was the questionnaire respondent.

3.29 Design Structured Interview Selection Discussion

Good matches were produced for pumps and agricultural machinery. The best match was pumps, both had very similar products with a good size match. Agricultural machinery had a close size match but the product were a little more different than pumps. Air conditioning was not a successful match - both product and size were different. It was hoped that this latter difference would enable some interesting issues to emerge. This concludes the description of the structured interview methodology.

3.30 Structured Interview Methodology Conclusion

The methodology adopted for the structured interviews provided a sound basis for the comparison and analysis of the critical factors determining the difference in performance of the structured interview firms. The rigour of the methodology meant that the comparisons of the matched pair companies are legitimate and produced valid results. The application of the methodology to several pairs of firms (five pairs in total) means that the reliability of the methodology was also strong. Further, the methodology allows for the comparison not only of the matched pairs but also across individual companies, across product types and ranges, across firm size, and across the CAD - nonCAD divide.

The novel methodology adopted here - the combination of a random questionnaire survey and two sets of structured interviews and the linking theoretical framework - will produce interesting results. The interaction between the two methods will produce some results which will be unique to the current study. It is highly unlikely that the methodology, of combining a random national survey with structured interviews, will be repeated. Having described the methodology adopted by the research the following three chapters present the results, starting with the survey.

CHAPTER 4

SURVEY RESULTS

4.1 Introduction

This chapter presents the results of the survey of the UK mechanical engineering industry. It does so following the format laid out in the theory chapter. The results of the survey on design intensity are presented first. Then the results for each of the four themes are given: product specification, organisation and co-ordination, consideration of production and CAD. Each of these themes is cut across by the results of the design performance analysis. The sections are individually introduced and summarised.

The research sought to determine the extent to which mechanical engineering firms design their own products - the overwhelming majority do, there being very few manufacture only subcontract firms. Design is also well institutionalised within the majority of firms (most have design departments and introduce one new product per year). Most firms used written product specifications, the rest supplemented them with verbal instructions. The most important aspects that firms considered in their product specifications were functional and engineering requirements along with product cost. Fewer than a quarter of firms considered production aspects in the specification. The majority of firms extensively involved design management, sales, marketing and designers in the drawing up of the product specification. However, the expertise and knowledge of production personnel are not included in the product specifications drawn up by companies.

The most frequent organisation structure in use was simultaneous engineering. Firms were equally split in the use of matrix organisation and integrated product-process design departments. The majority of firms used meetings as the design co-ordination mechanism. Project teams, product champions and ad-hoc consultation/ visits were each in use by nearly a half of firms. Designers, sales, production engineering, production management and design management were the personnel most heavily involved in design - production co-ordination. Most firms had good co-ordination between design and production. Factors which hindered co-operation were different expectations, departmental barriers and physical separation. Improvement factors were common expectations, removing departmental barriers and physical closeness. This analysis implies that the differentiation between design and production departments had created a management problem for firms.

The research found that the design stages of a product's development could be summarised as follows: The conception stage was when the specification of the product was considered, with some attention given to how it fitted in with existing products and components. The detailed design stage was when the practicalities of the design were worked out - ie. the "what to make" was designed. The requirements of production were also given some consideration - ie. production processes and assembly techniques. The prototype stage was where the costs of what was being made were honed, still keeping the product within specification. Now production aspects were given full consideration: the "practicalities of production" - how are we going to make them, how many, on which machines and by whom. The pre-production stage was for making the products and refining the process of making them. Production was focussed on making the products and their quality. It was found that the prototype design stage was pivotal - where the balance shifted from design aspects to production aspects. The research also found that production engineering were more extensively involved in the design process the closer it moved toward manufacture. Companies' current practice is thus to consider the manufacture of a product after it has been designed.

Although there is a reasonably high usage of computer-aided design in the mechanical engineering industry, some 60%, this is still not widespread enough for it to fully transform the interface. Although CAD had the potential to improve large parts of the design process, in for example conceptual and functional design, CAD in the mechanical engineering industry is only used for drawing. Further, most firms are only using the 2D drawing ability of CAD and are not using its 3D capability. The more sophisticated uses of CAD, for design for assembly etc, were not taken up by firms. This means that the real gains of CAD - 3D design and simulating finished products and their assembly before anything is made is not even approached by companies. It was found that CAD use was associated with high levels of modification. This issue was used to structure the structured interviews discussed in the next chapter.

4.2 Design

This section examines the issue of whether or not mechanical engineering companies design their own products, or simply act as subcontractors for other firms which carry out the design. It also looks at the extent of design activity, that is, how much design firms carried out, and what type of design - engineering or aesthetic, and the institutionalisation of design in terms of departments. It also investigates the factors, establishment employee size etc, that influenced a firm's design activities.

4.2.1 Extent of Design

This section reports on the result of the survey in determining the extent of design within the mechanical engineering industry and within firms. In the latter case several measures of design activity were used in order to determine the extent of firm's design.

4.2.1.1 Design of Products

First, the survey sought to determine if the responding firms actually designed the products they manufactured. This inquiry would tell us the proportion of mechanical engineering firms that carried out sub-contract work which involved no design input by the firm itself. The survey results, shown in Figure 4-1, show that 85% of firms designed the products they manufactured. Conversely, 13% of firms did not design the products they manufactured - and these can be considered to represent the proportion of sub-contract firms in the industry. Only two per cent of firms did not reply to this question. Hence, the survey showed that the overwhelming majority of mechanical engineering firms carried out the design of the products they manufactured.

Fig 4-2: Aesthetic Design

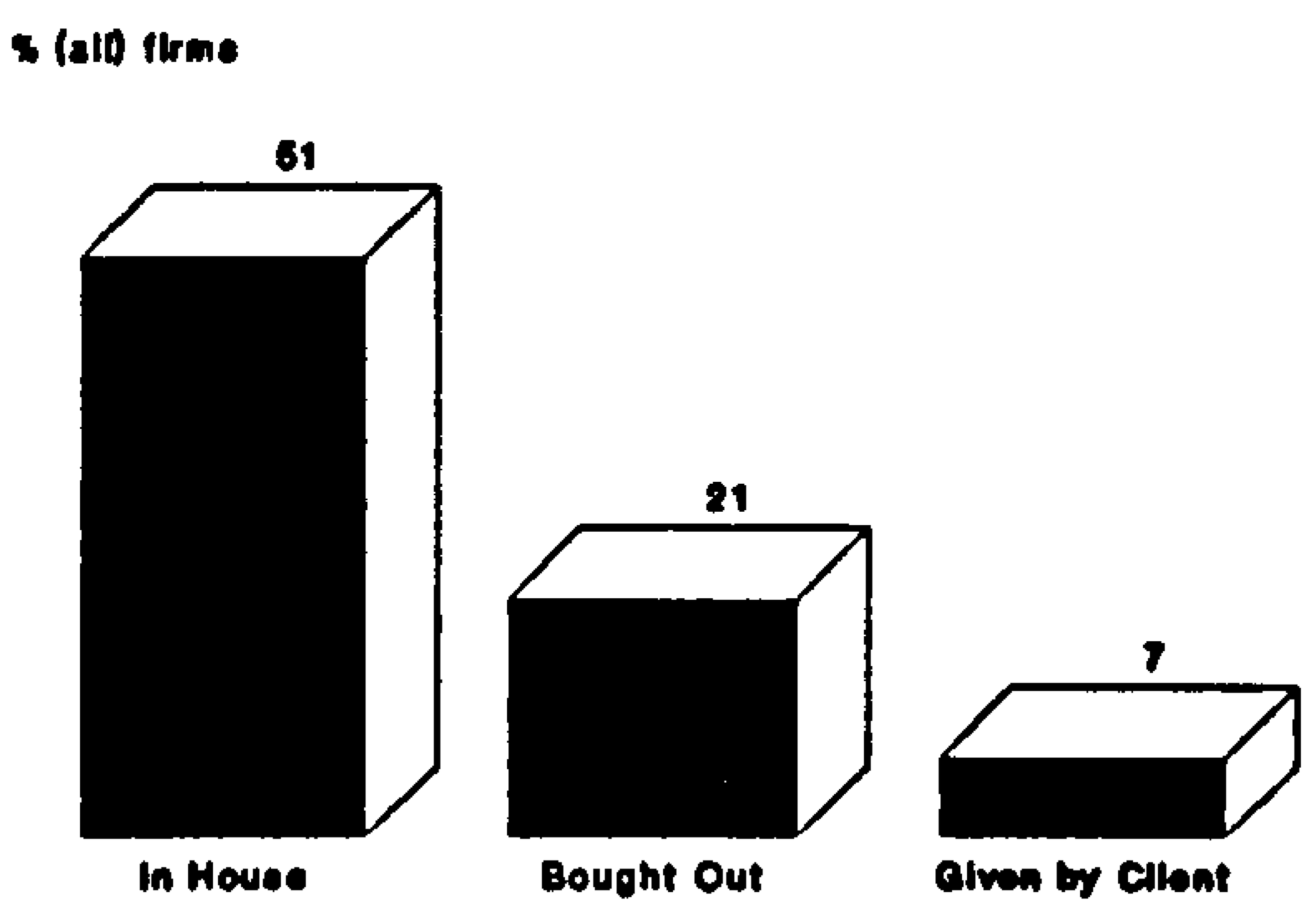


Fig 4-2: Engineering Design

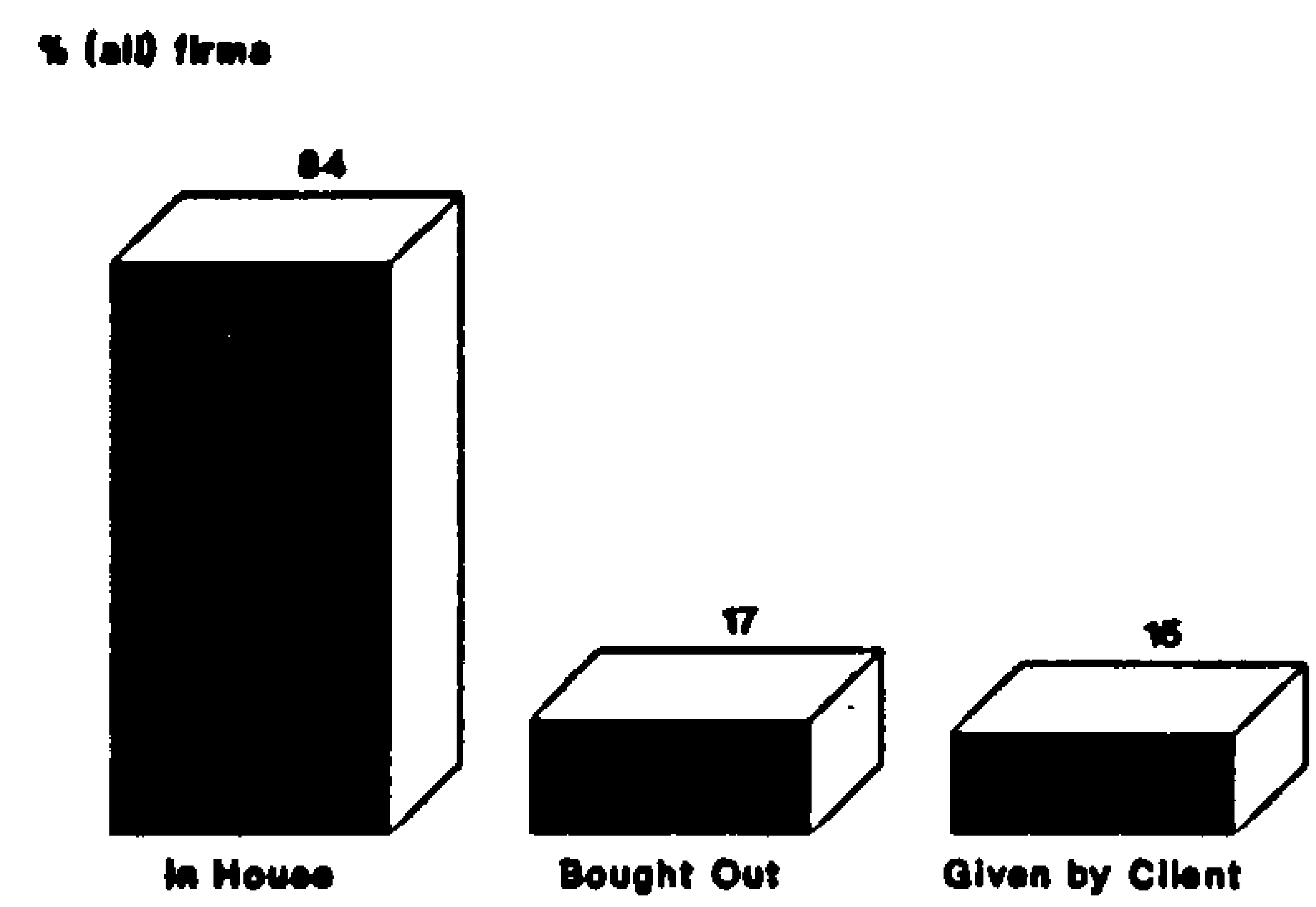
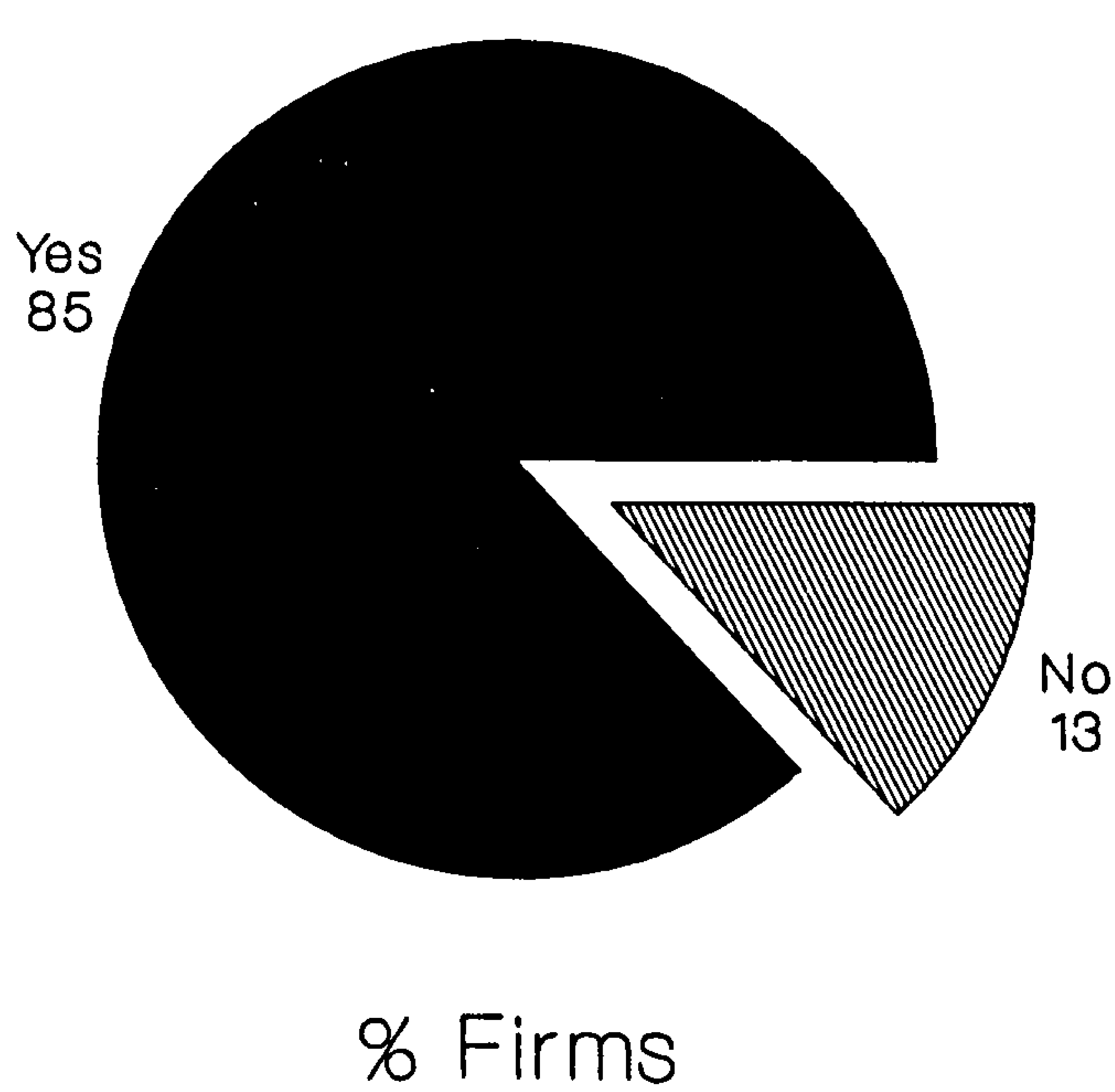


Fig 4-1: Company Design its Products



4.2.1.2 Types of Design - Engineering & Aesthetic

Second, the survey sought to determine the extent of design activities within firms. Thus, the types of design activity, engineering and aesthetic, carried out by the firms was investigated. The results are shown in Figure 4-2. Again the overwhelming majority of firms carried out engineering design (84%). Also a half of all firms carried out aesthetic design in-house. Roughly equal proportions of firms bought their designs in from outside (17 and 21% respectively). Twice as many firms (15%) received their engineering designs from their customers, as opposed to aesthetic design (7%). Hence, once again the overwhelming majority of mechanical engineering firms carried out engineering design in-house, with a majority carrying out aesthetic design in-house.

4.2.1.3 Departments of Design and Design Consultants

The survey went on to investigate the degree of institutionalisation of design within the firms. That is, to determine if design, development and R&D departments existed within the companies. The results are shown in Figure 4-3. Again the overwhelming majority of firms had design departments on site (74%). Only a small minority (6%) did not have a design department. Also only a minority (5%) had access to a design department located at another site. Concerning development departments the results were similar. However, only just over half of firms had development departments (54%). The proportion not possessing development departments went up to 10% with those with access to a department at another site being similar to design departments. R&D showed a similar pattern, and again the proportion of firms possessing R&D departments fell to 39%. The proportion without rose to 16%, again with a similar number having access to off-site R&D.

The survey also investigated the use of design consultants by firms. Equal proportions of firms said they used external design consultants as did not (42%). Sixteen per cent of firms did not reply to the question. (See Figure 4-4)

Hence, the overwhelming majority of mechanical engineering firms have design departments. Half of firms had development departments and 40% had R&D departments. It can be concluded that design was well institutionalised for the majority of mechanical engineering companies. Hence, it can be inferred that most companies had found that the amount of design work they were carrying out necessitated that the activity be formalised and institutionalised with the creation of a design department.

Fig 4-3: Design Department

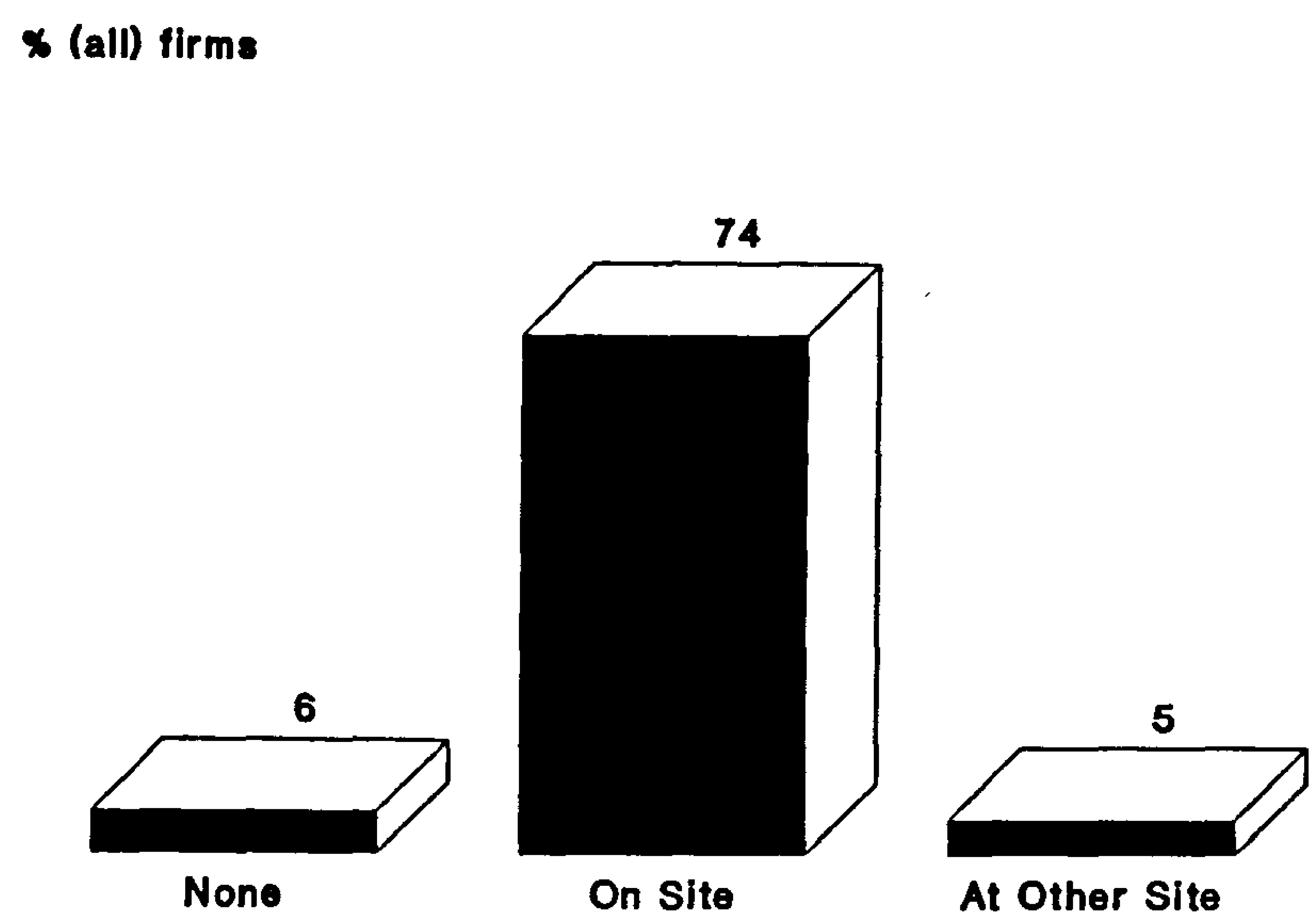


Fig 4-3: R&D Department

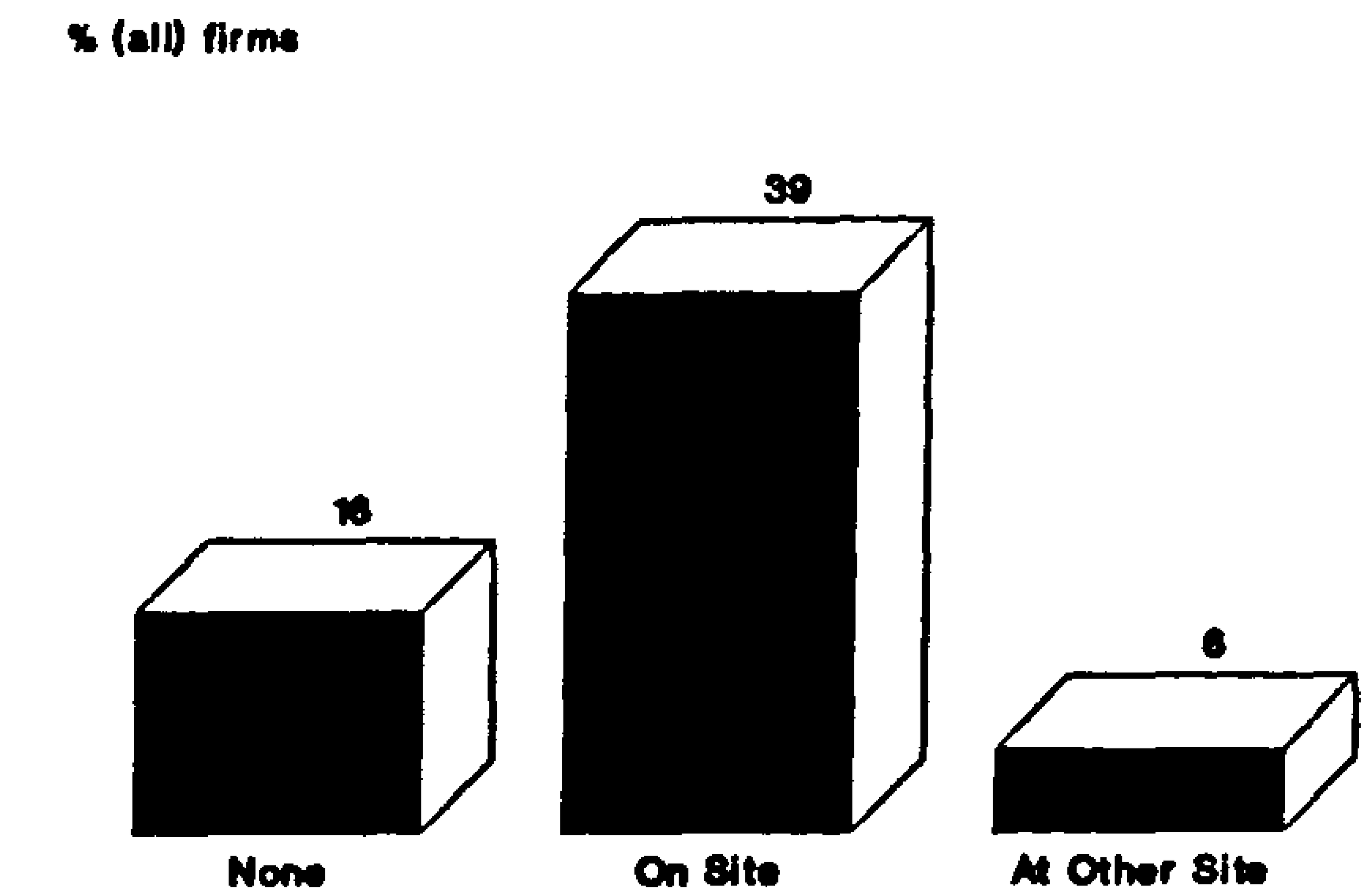
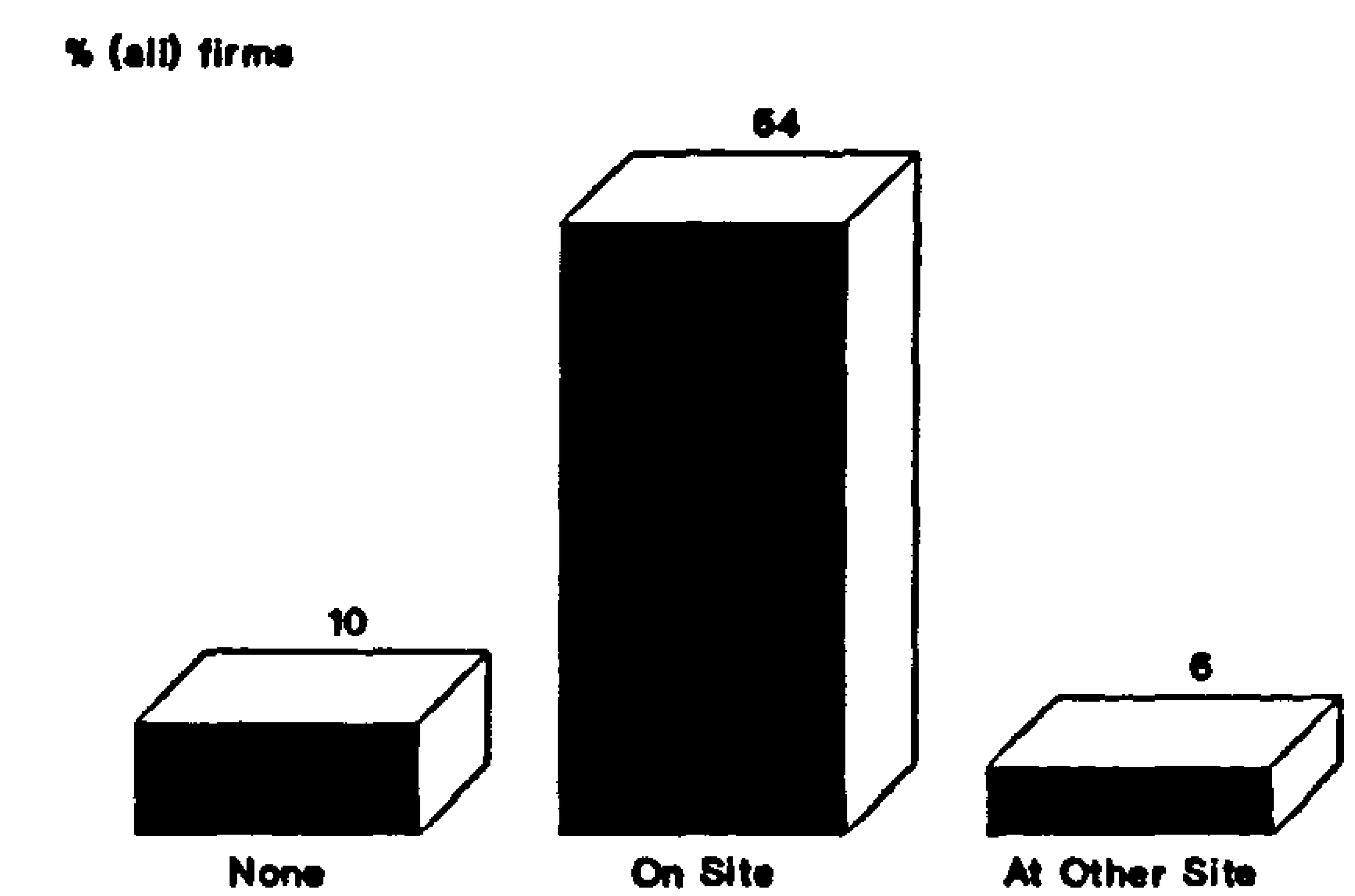


Fig 4-3: Development Department



4.2.1.4 Factors Affecting Extent of Design

In analysing the results of the survey explanations for the distribution of design activity were sought. The principal influence upon the amount of design work a firm carries out was posited to be the number of employees of a firm. The analysis of firms designing their own products by (site) employee size is shown in Figure 4-5. This shows that only in small firms with less than 20 employees did the proportion of firms designing their products fall below 80% (to 60%). Only two other size bands showed results discontinuous with the 90%+ proportion of the remaining size bands - 20-49 and 200-499 site employees. There is, as yet, no explanation for this. The result of 82% for 20-49 is, however, consistent with the result of 60% for the very small firms. Thus, the majority of all firms in each size band designed their own products, with only the smaller firms (less than 50 employees) being more likely not to design their own products. The analysis was extended to in-house engineering and aesthetic design (Figure 4-6). Somewhat similar proportion of mid-sized firms carried out in-house engineering and aesthetic design respectively.

4.2.2 Design Intensity

Taking as a measure of design intensity, new products introduced per year, showed that most firms introduced one product per year. Significant proportions of firms introduced two and three products per year. After ten products per year the proportion of firms fell to 1%. The extension of this measure up to 99 new products per year raises questions as to whether the firms could cope with this level of design activity. More than twenty products per year would be unusual. It can be said that virtually all companies designed at least one new product per year. Significant proportions of firms introduced two and three products per year.

Fig 4-4 Design Consultants by Site Empls

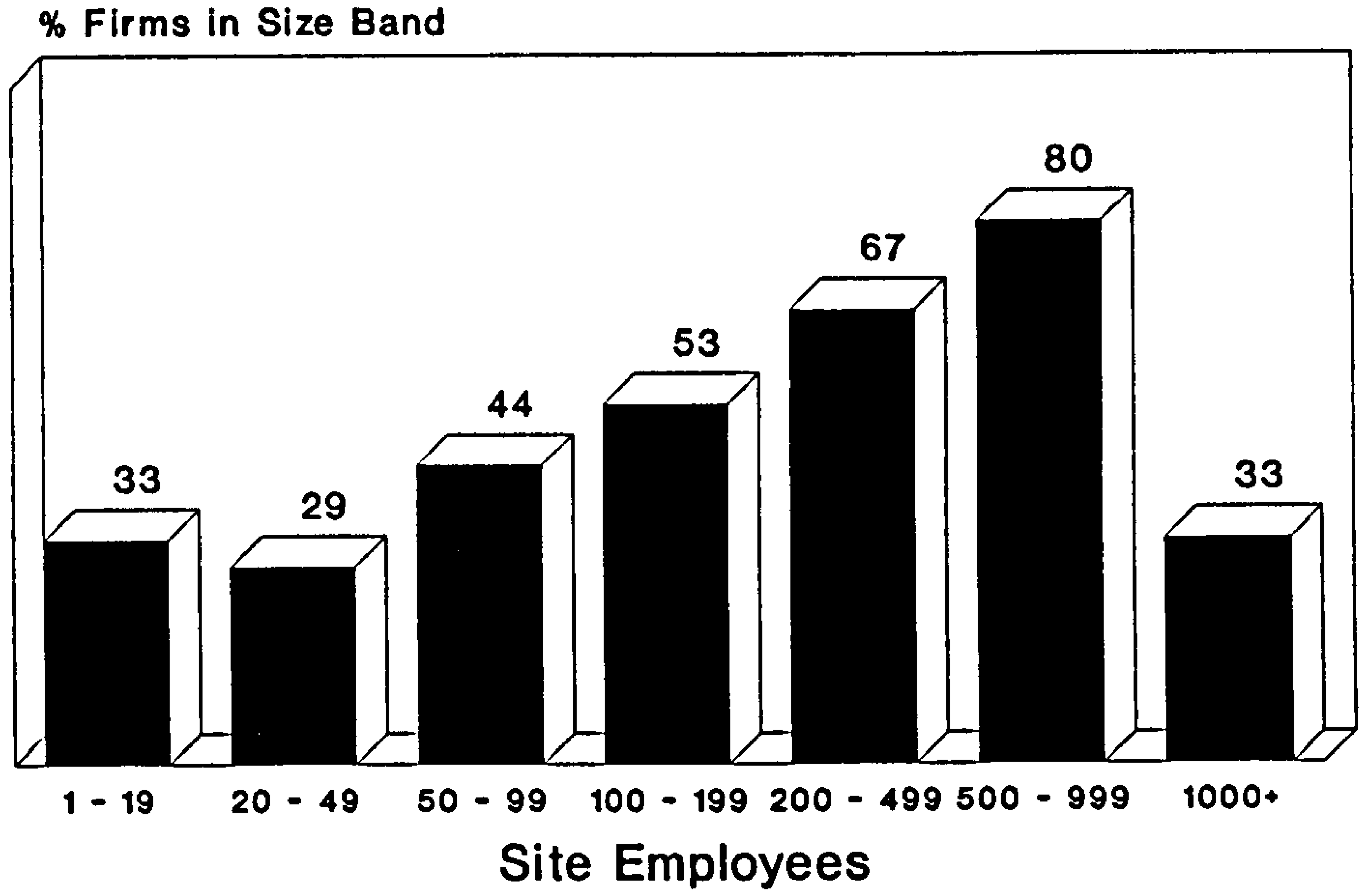
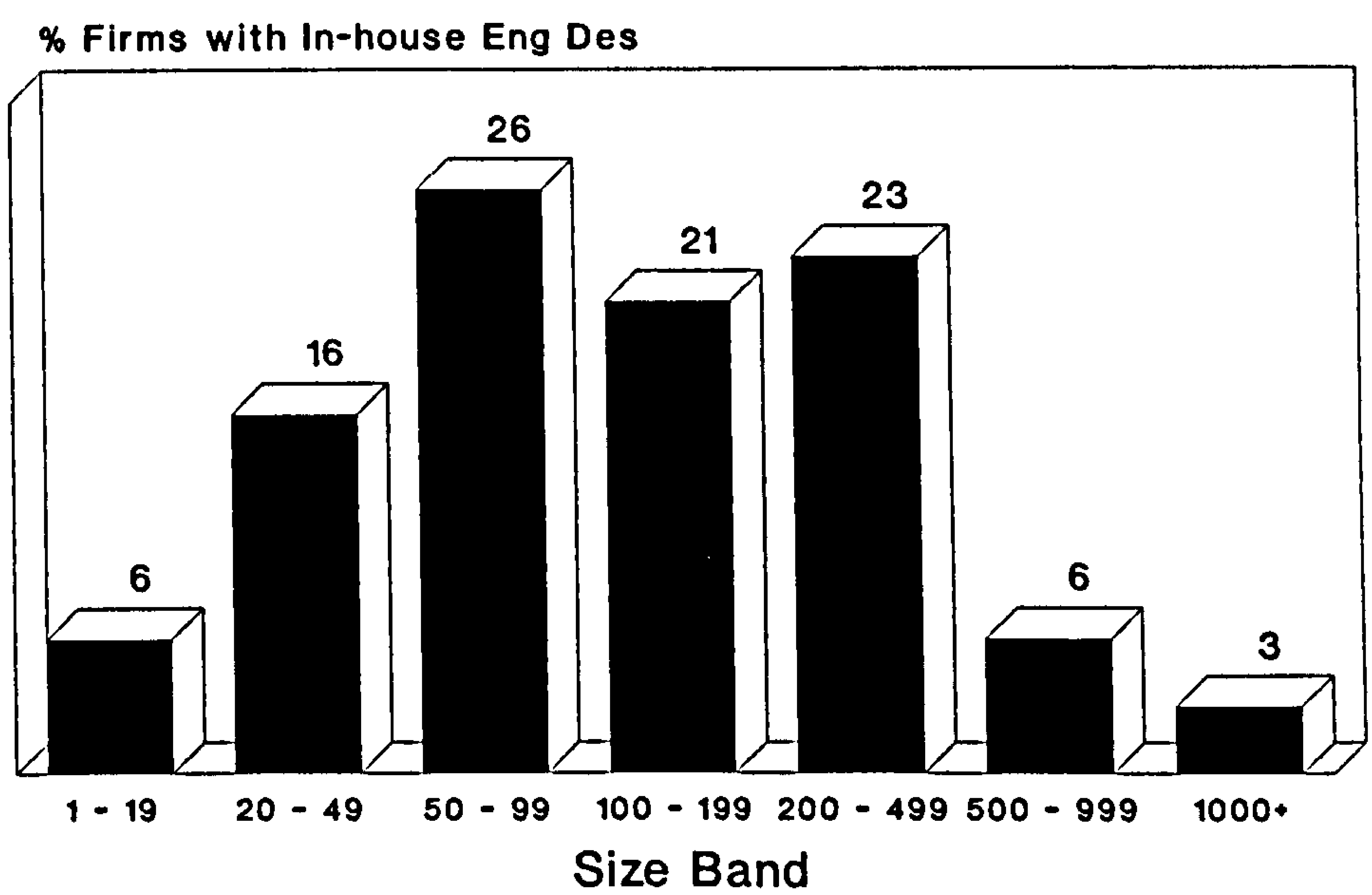


Fig 4-5 Engineering Design by Site Empls



4.2.3 Summary

The survey shows that the overwhelming majority of mechanical engineering firms carried out the design of the products they manufacture. Again the overwhelming majority of firms carried out engineering design in-house, with a majority carrying out aesthetic design in-house.

The overwhelming majority of mechanical engineering firms have design departments. Half of firms had development departments and 40% had R&D departments. It can be concluded that design was well institutionalised for the majority of mechanical engineering companies. Hence, it can be inferred that most companies had found that the amount of design work they were carrying out necessitated that the activity be formalised and institutionalised with the creation of a design department.

The majority of all firms in each size band designed their own products, with only the smaller firms (less than 50 employees) being more likely not to design their own products. Hence, size did not determine whether firms designed their own products or not.

Virtually all companies designed at least one new product per year, with significant proportions of firms introducing two and three products per year.

4.3 The Product Specification

This section concentrates on the first theme of the research - the product design specification. As discussed in the theory chapter the conceptualisation of the product design process into two separate phases - product specification and product design - has been well formulated in the literature (Pawar 1985, Topalian 1980, Hollins & Pugh 1990). Product specifications are a key element of the product design process. They form the first stage of the product design process and their influence lasts throughout it. The use of them greatly influences the effectiveness of new product introduction. It is thus important to investigate their use, content and impact upon product design effectiveness. The research investigated the compilation of product specifications by companies and the characteristics of the firms using them. The format of the product specification was also investigated (written, verbal or both). Again the characteristics of firms using the different formats was examined. This section presents the analysis and results from the survey of the UK mechanical engineering industry for the product specification. It also considers the influences upon the format of the product specification. The section concludes with implications for the use of product specifications. The first subsection analyses the characteristics of firms using product specifications.

4.3.1 Characteristics of Firms Compiling Product Specifications

This section analyses the characteristics of firms who used product specifications. The majority of firms compiled a product specification. Firms can be characterised by their regional distribution, by establishment size, by sales turnover, by the age of production equipment, by type of process technology and finally by type of product manufactured. Each of these characteristics will be discussed in turn. In terms of regional distribution the analysis showed that regional location did not influence firms in compiling specifications (see Figure 4-7). The two regions that contained significant proportions (approximately 30%) of firms who did not compile specifications were Yorkshire and Humberside and the South West, although only small numbers of firms were located in each of these regions. Eighty two per cent of firms in the South East, where the largest proportion of survey firms were located, compiled specifications.

Fig 4-7 Specification & Region

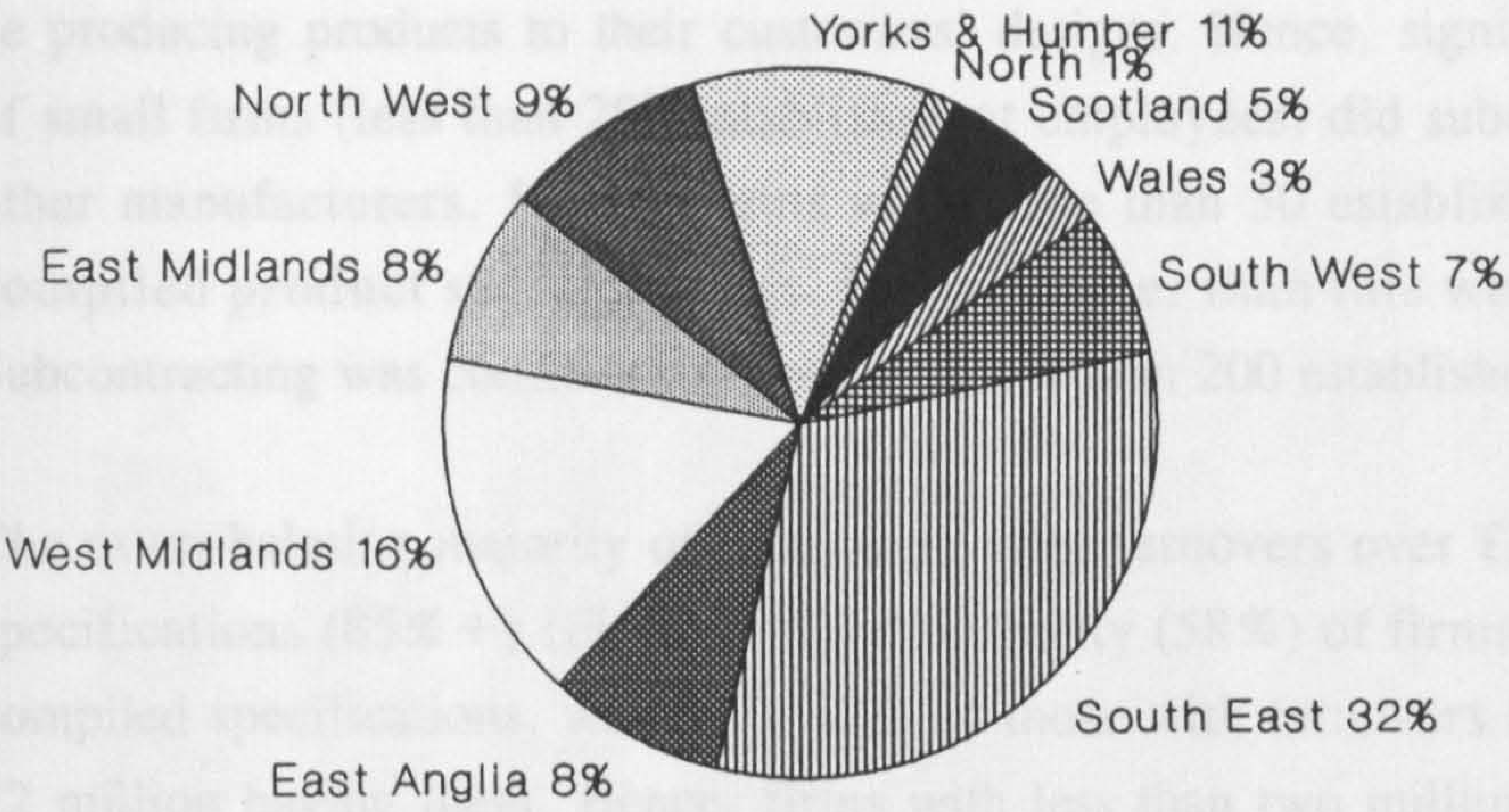
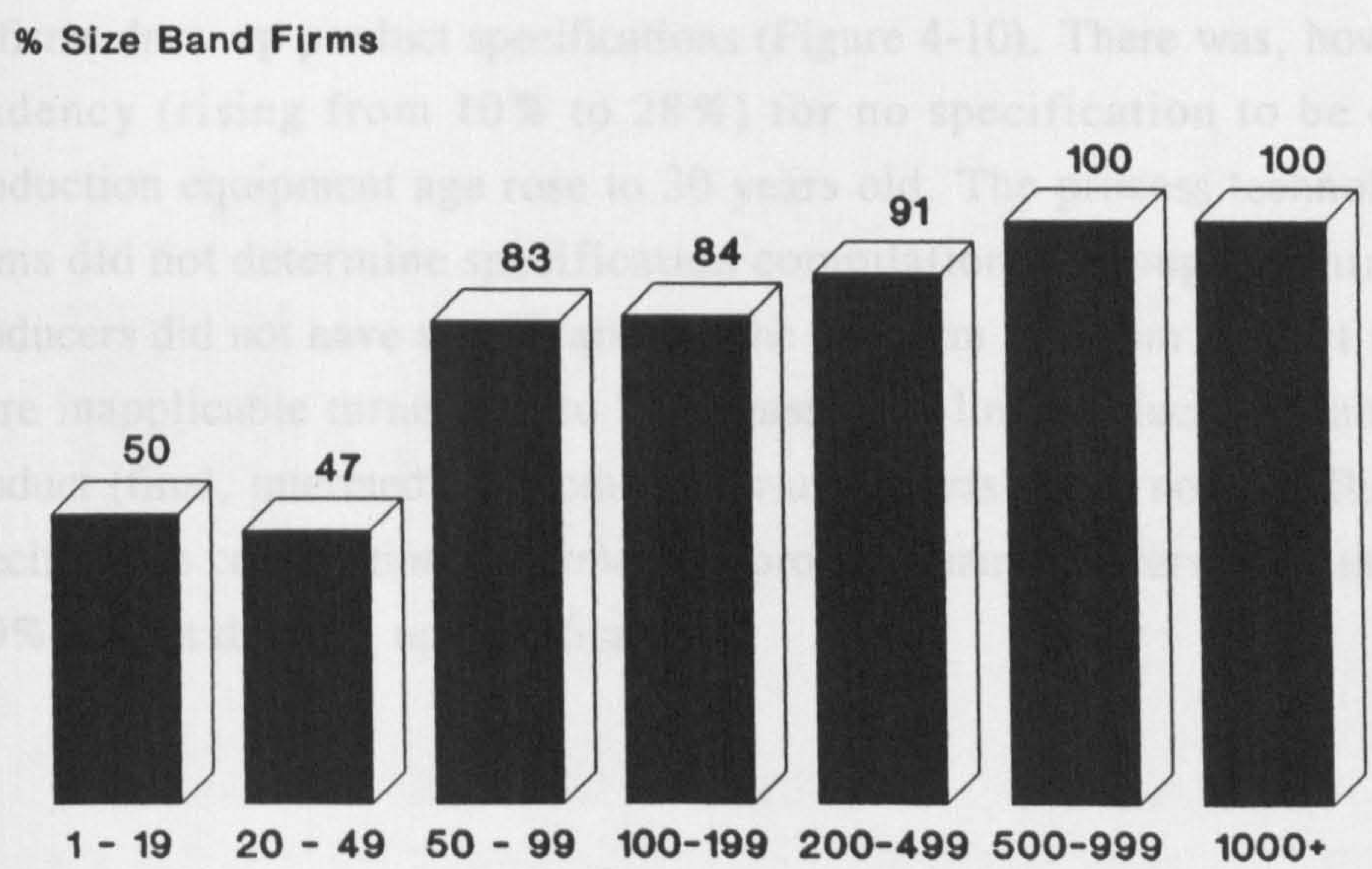


Fig 4-8 Product Specification & Employee



The analysis of product specification use by size of firm, as measured by establishment employees, showed that the overwhelming majority of firms with more than 50 employees complied product specifications (Figure 4-8). Half the very small firms (1 - 19 establishment employees) compiled specifications, one third did not compile them and 17% said it was inappropriate. Just over half the establishments with 20 to 49 employees did not compile specifications, all the rest did. Sixteen per cent of establishments in the 50 to 99 and 100 to 199 size bands did not compile specifications. These firms, and the very small ones, can thus only be producing products to their customers' designs. Hence, significant proportions of small firms (less than 200 establishment employees) did subcontract work for other manufacturers. Hence, firms with more than 50 establishment employees compiled product specifications, firms smaller than this were less likely to. Subcontracting was confined to firms with less than 200 establishment employees.

The overwhelming majority of firms with sales turnovers over £2 million drew up specifications (85%+) (Figure 4-9). A majority (58%) of firms under £1 million compiled specifications, with only 42% of those with turnovers in the range £1 to £2 million having them. Hence, firms with less than two million pounds turnover were more likely not to have product specifications. A further analysis of the format of the product specification for these smaller firms (<£2m) showed that around 15% of firms who had specifications used only verbal ones. The majority of the smallest firms (£0-1m) supplemented the written specification with verbal instructions.

The analysis of production equipment age showed that the overwhelming majority of firms drew up product specifications (Figure 4-10). There was, however, a mild tendency (rising from 10% to 28%) for no specification to be compiled as production equipment age rose to 30 years old. The process technology used by firms did not determine specification compilation, although, a third of one-off producers did not have specifications. The one firm to whom product specifications were inapplicable turned out to be a mass/flow line producer. Again the type of product (final, intermediate, both or consumer) was found not to influence product specification compilation. Intermediate product manufacturers were the most prone (30%) to not drawing up specifications.

Fig 4-9 Specification & Sales Turnover

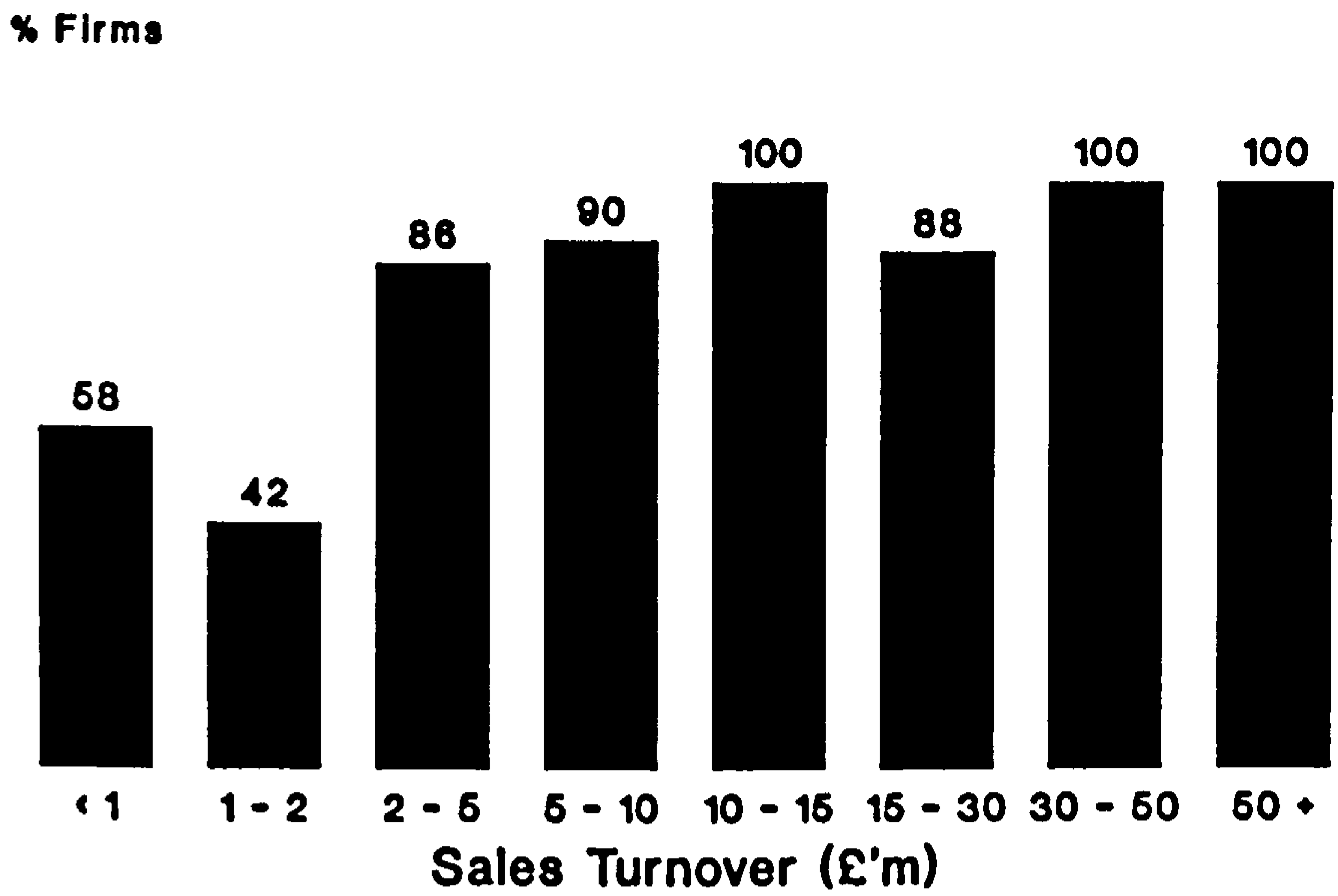


Fig 4-10 Specification-Prodctn Equip Age

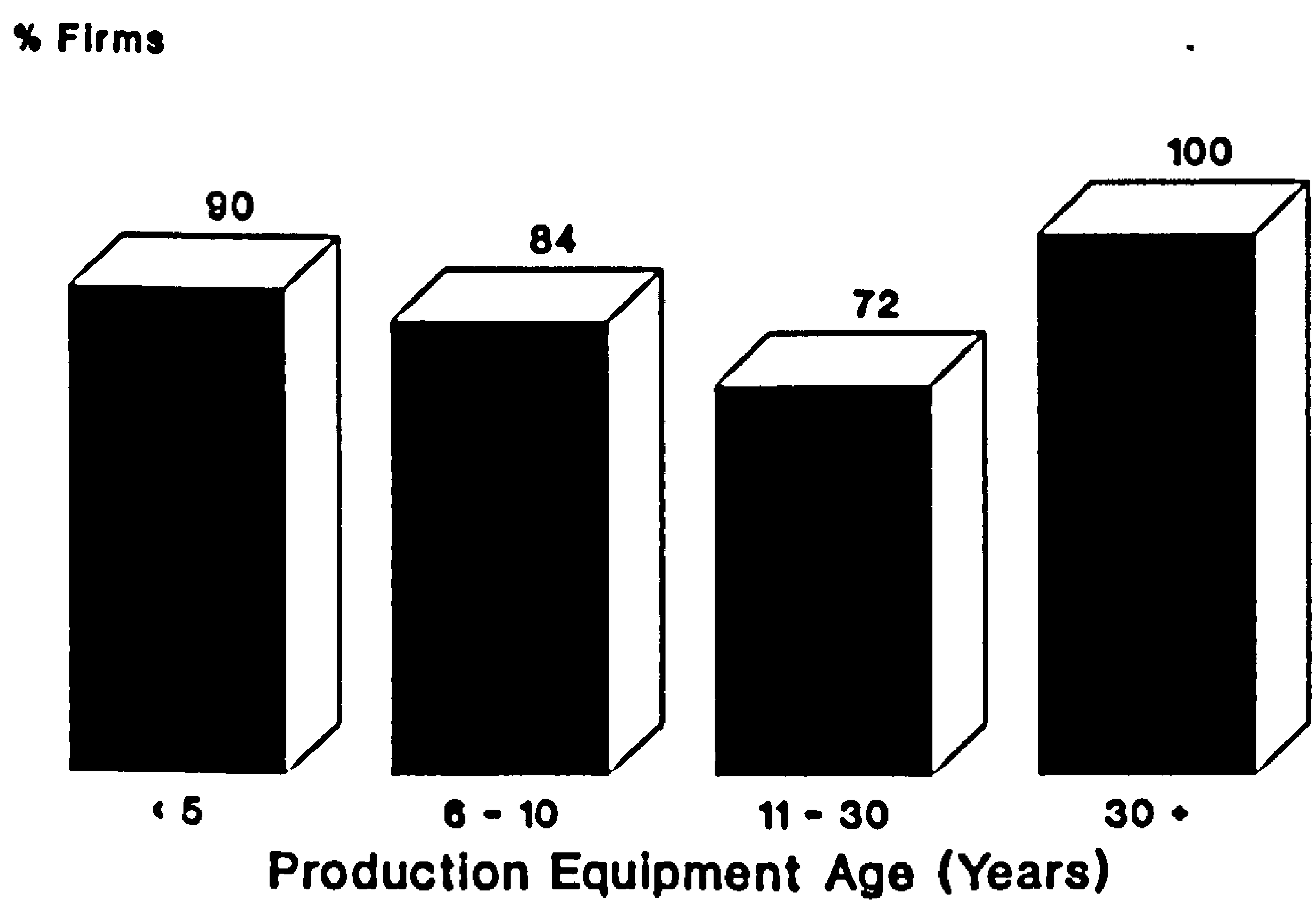


Fig 4-11 Product Specification New Prods

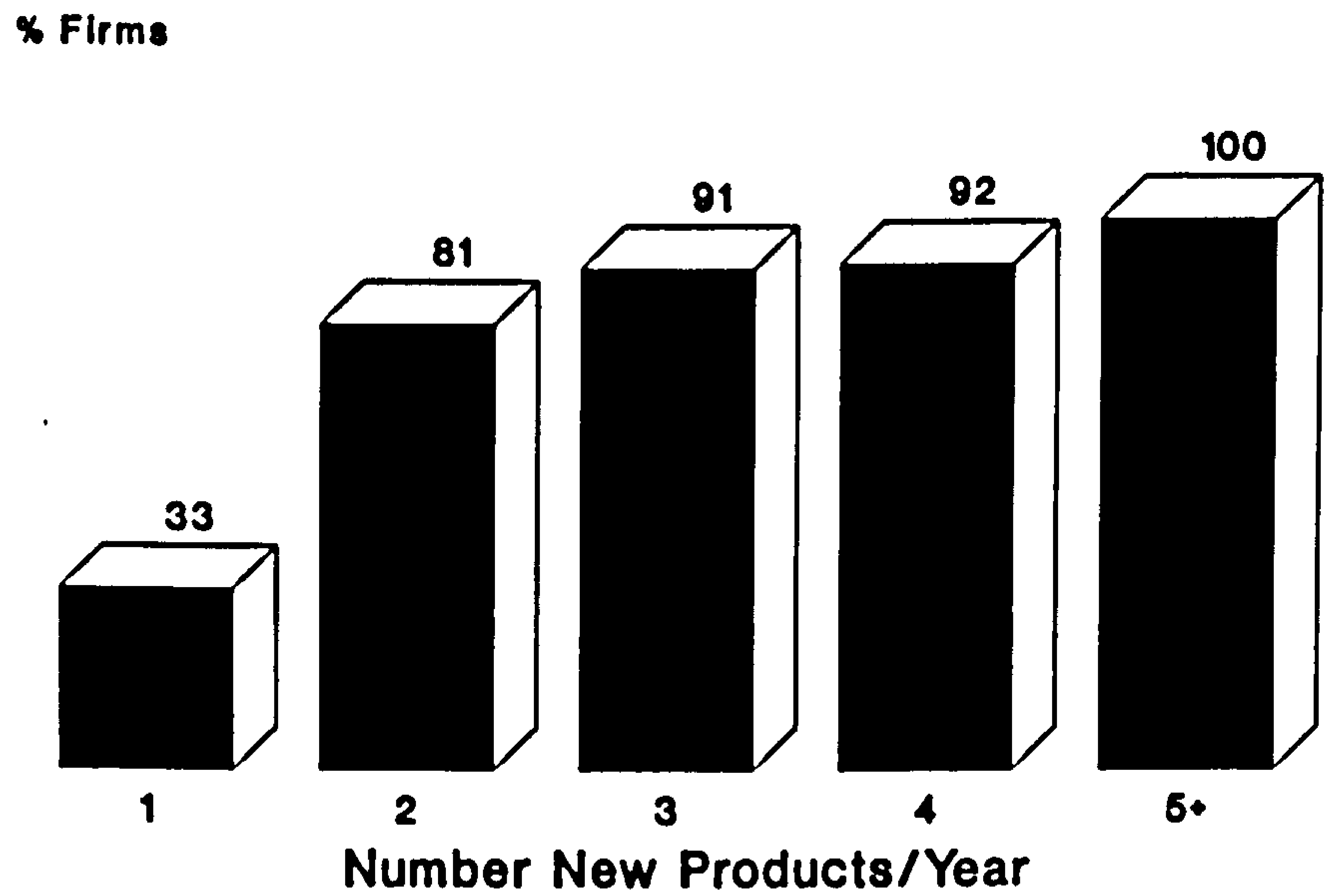
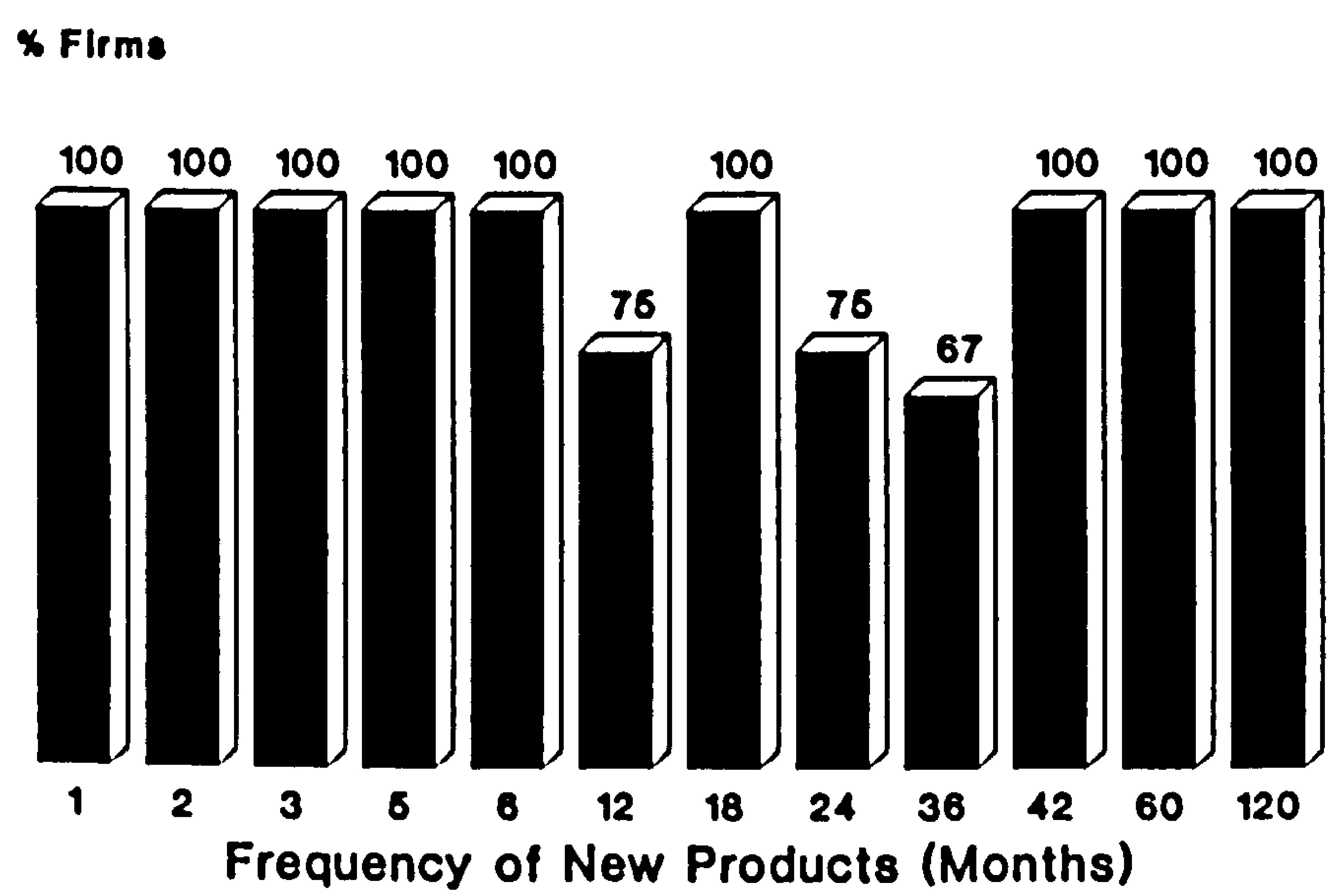


Fig 4-12 Specification-Product Frequency



The number of new products a firm introduced per year did not influence the compilation of product specifications. All firms with more than three new products per year drew up specifications (Figure 4-11). Only five per cent of firms with one new product did not draw up product specifications, this being one per cent for two and three product firms. Using the alternative definition of frequency of new product introduction, 25% of firms introducing a new product every one and two years did not compile specifications, as was the case with 33% of three year interval firms (Figure 4-12). Thus, both measures show that the number of new products a firm introduces did not influence product specification use. This is significant as it implies that even when firms are introducing quite a number of new products, specifications were drawn up for each one. This concludes the analysis of the characteristics of firms compiling product specification. The next section analyses the factors influencing the format of the specification drawn up.

4.3.2 Format of the Product Specification

This section analyses the format of the product specifications that were compiled by firms. The majority of firms compiled a written product specification (see Figure 4-13). Forty two per cent of firms compiled verbal and written product specifications. Only three per cent of firms used a verbal specification. This confirms the results of an earlier survey carried out by Pawar (Pawar & Riedel, 1990). This survey was a survey of manufacturing industries in the West Midlands. It found that 48% of respondents compiled written specifications, 46% written and verbal and verbal only 13%. It can be concluded that the majority of firms compiled written specifications with a significant minority of firms supplementing this with verbal instructions. Only a small minority of firms did not compile product specifications. Further analysis by establishment size (see Figure 4-14) showed that the smaller firms (1 to 50 employees) were the ones using verbal only specifications. Also the overwhelming majority (75%) of very small establishments (<20 employees) used written and verbal specifications. The majority of firms in all size bands bar 500 to 999 employees used written specifications, with the minority using both. Hence, size only influenced the format of product specifications in the case of small and very small establishments where verbal specifications became more prominent.

Fig 4-13 Product Specification Format

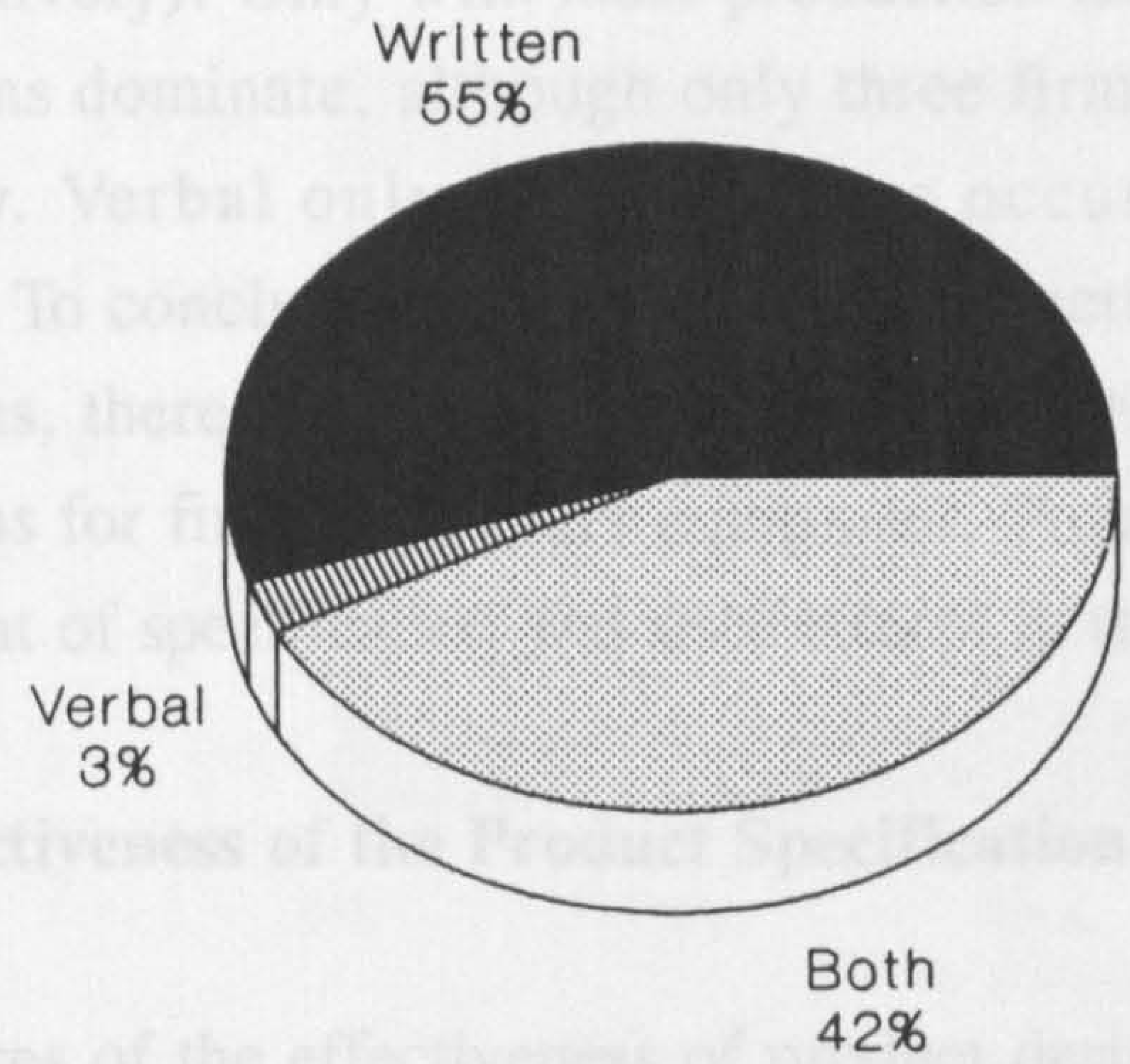
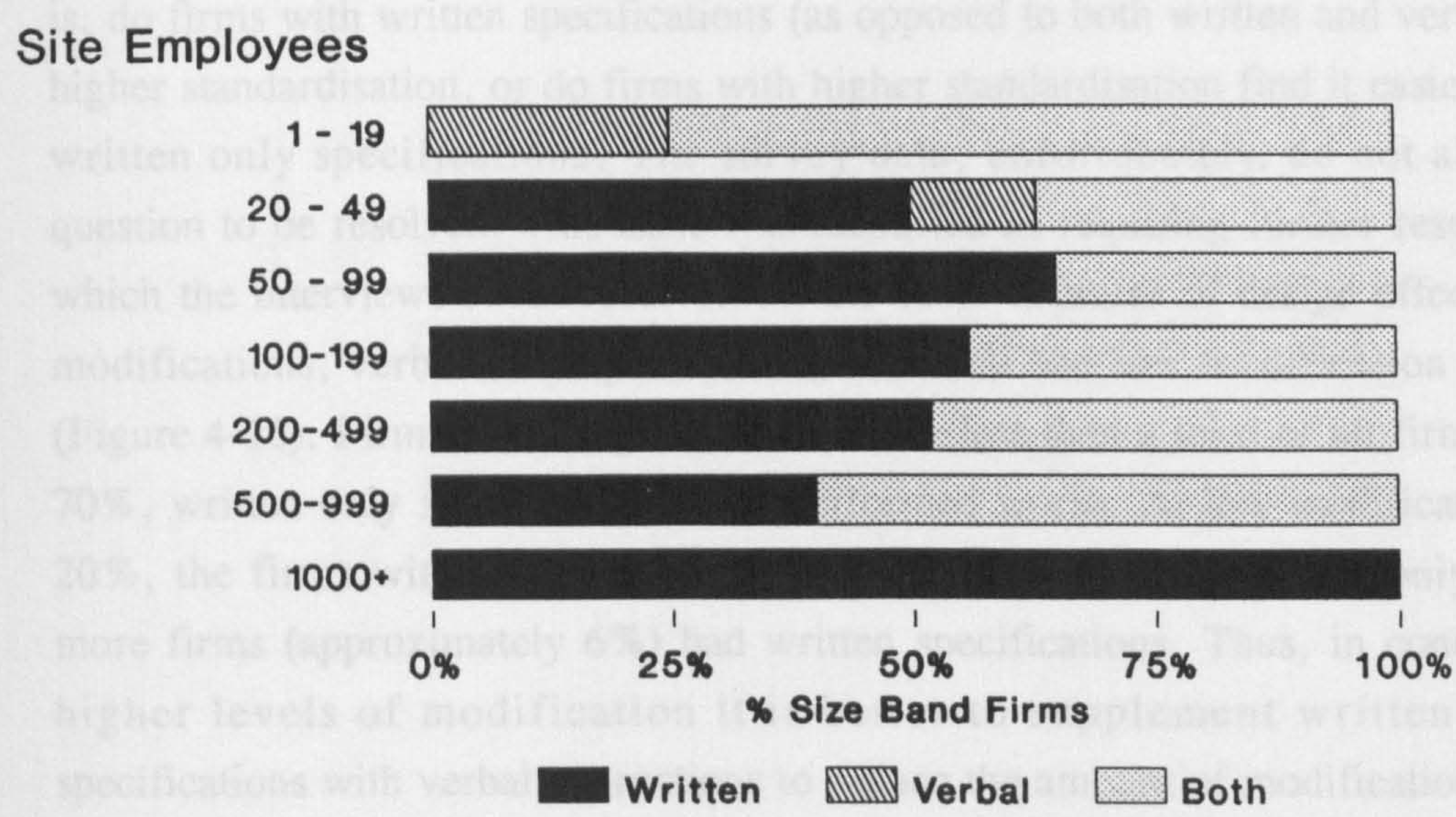


Fig 4-14 Product Specification-Employees



The influence of two other factors on the format of the product specification was also examined - the age of production equipment and the type of process technology in use. The overwhelming majority of firms with new production equipment (less than five years old) had written specifications. But firms with older equipment (6 to 30 years old) were equally divided between written and both written and verbal specifications. Firms with verbal only specifications had equipment less than ten years old (this only applied to two firms). The majority of both one-off and batch process technology firms had written specifications (52 and 58% respectively). Only with mass production technology did written and verbal specifications dominate, although only three firms in the survey had this process technology. Verbal only specifications occurred with one-off production technology. To conclude, firms with new production equipment used only written specifications, there was no difference between written and both written and verbal specifications for firms with older equipment. Process technology did not determine which format of specification was used except in the case of mass production.

4.3.3 Effectiveness of the Product Specification

Two measures of the effectiveness of product design will be used to analyse firms' performance. These are the amount of modification carried out to a design while it is in production and the number of standard components in a design. Using this latter measure, firms with written specifications tended to have more standard components, the exception being 61 to 80% standard components where firms with both written and verbal specifications were in the majority (Figure 4-15). All firms with verbal only specifications had low standardisation, 0-20%. The question then is, do firms with written specifications (as opposed to both written and verbal) have higher standardisation, or do firms with higher standardisation find it easier to have written only specifications? The survey data, unfortunately, do not allow this question to be resolved. This issue was identified as requiring further research and which the interviews could resolve. On the other measure of design effectiveness, modifications, verbal only specification firms all had low modification (<20%) (Figure 4-16). Firms with "high" modification (less than a third of all firms), 21 to 70%, written only specification firms performed worse. At low modification, 0 to 20%, the firms with written or both were almost equally divided, only slightly more firms (approximately 6%) had written specifications. Thus, in conclusion at higher levels of modification it is better to supplement written product specifications with verbal instructions to reduce the amount of modification. At low levels of modification it is slightly better not to supplement written specifications. This concludes the analysis of the specification format and the influences upon it.

Fig 4-15 Specification & Standardisation

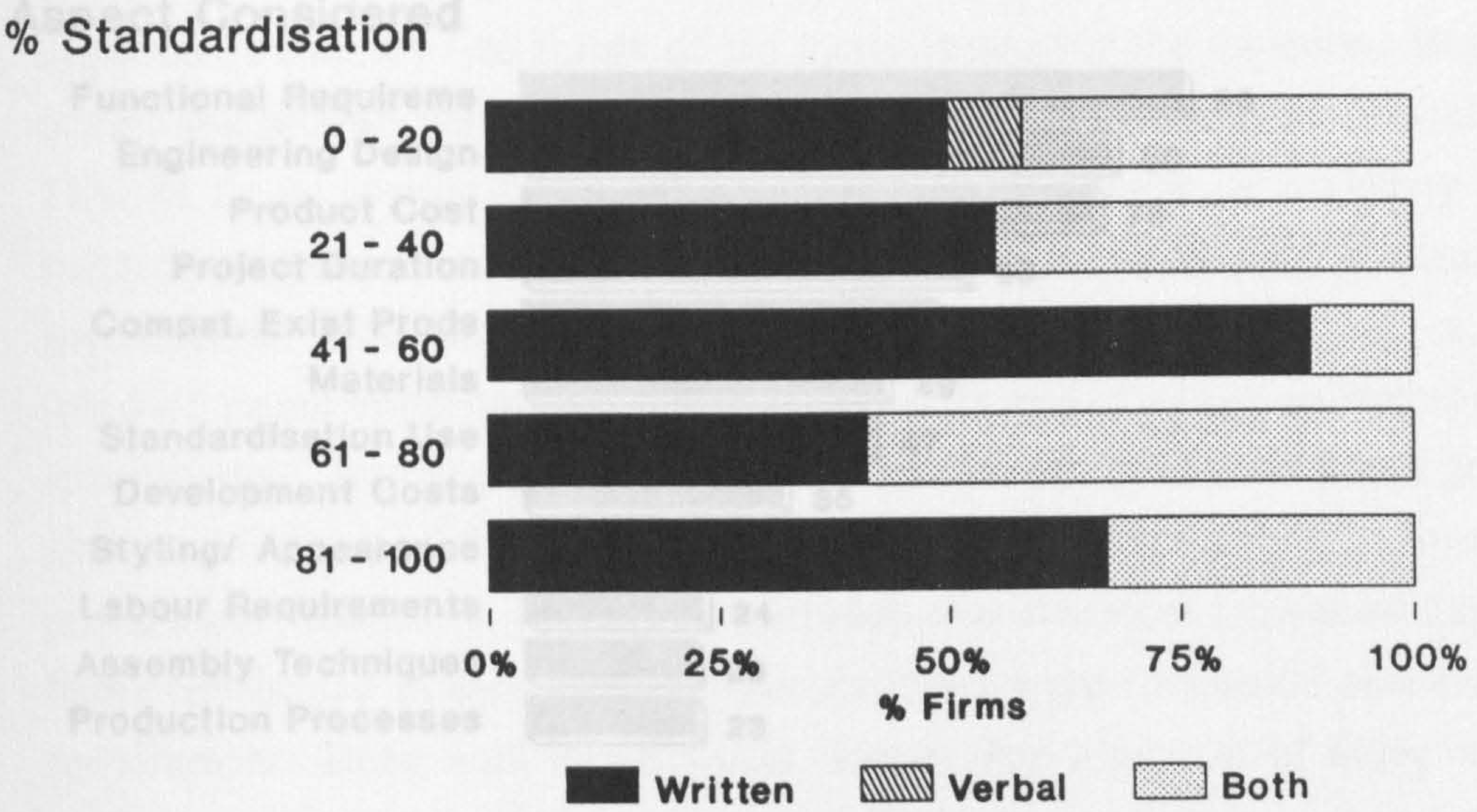


Fig 4-16 Specification & Modification

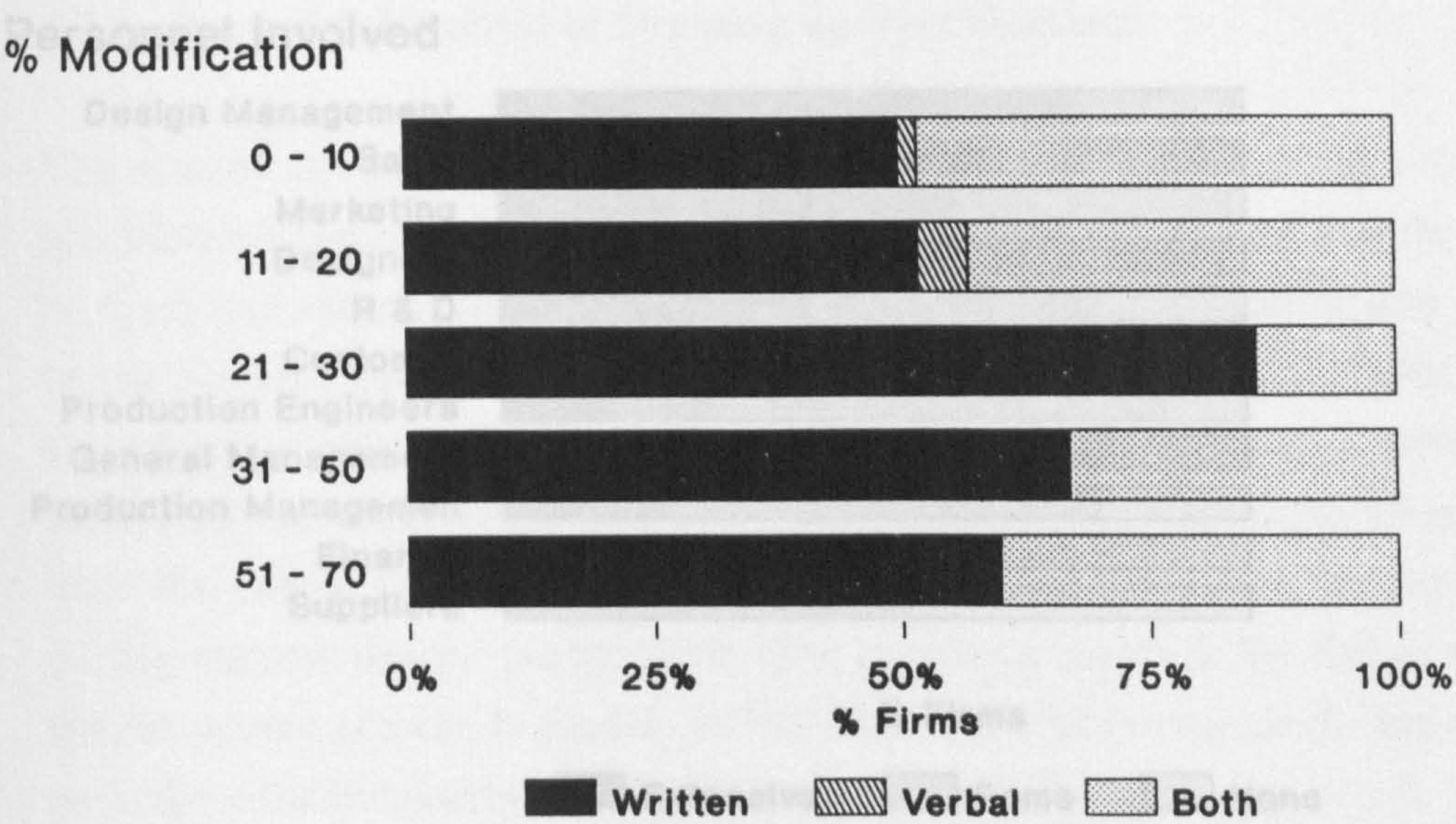


Fig 4-17 Product Specification Aspects

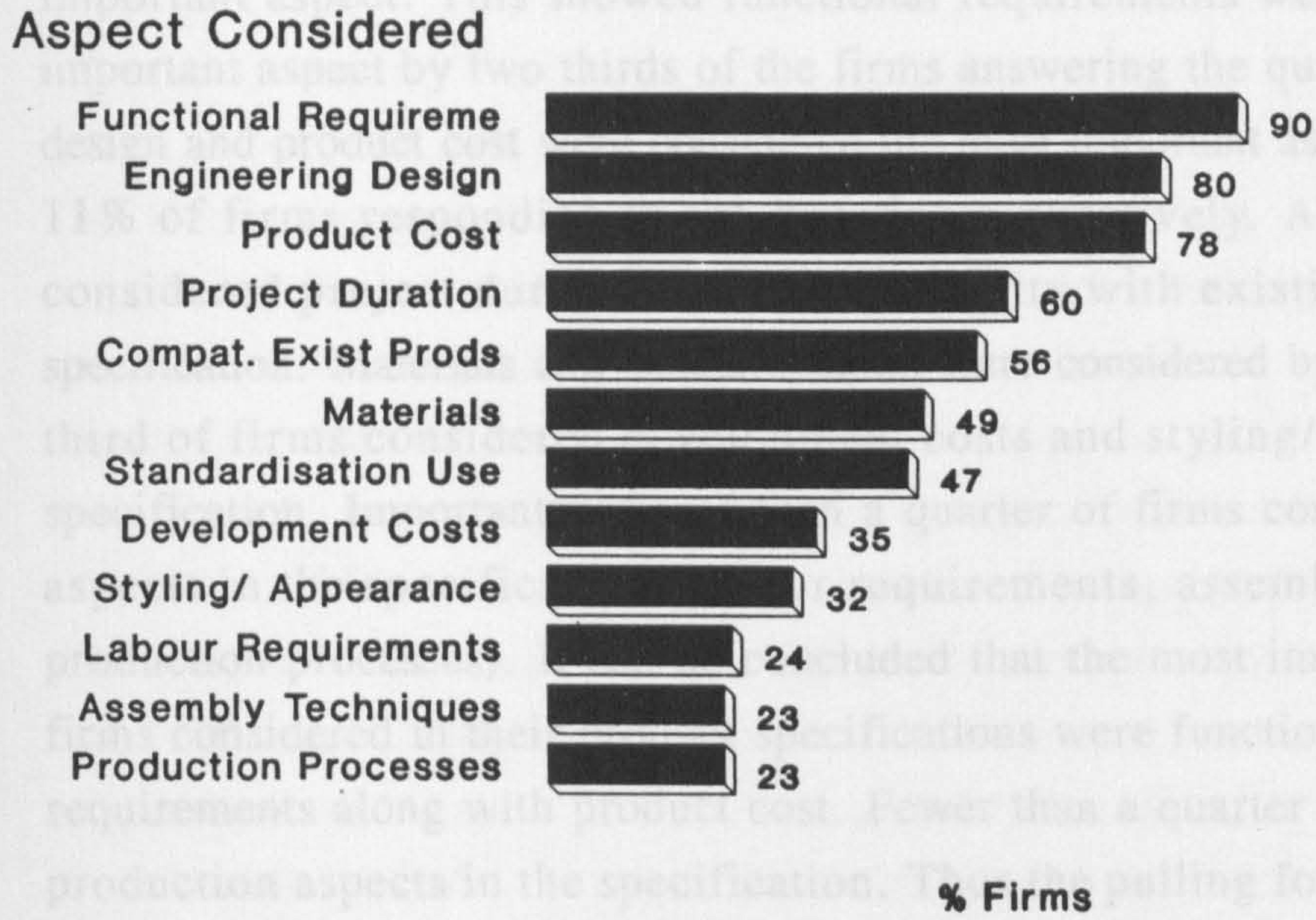
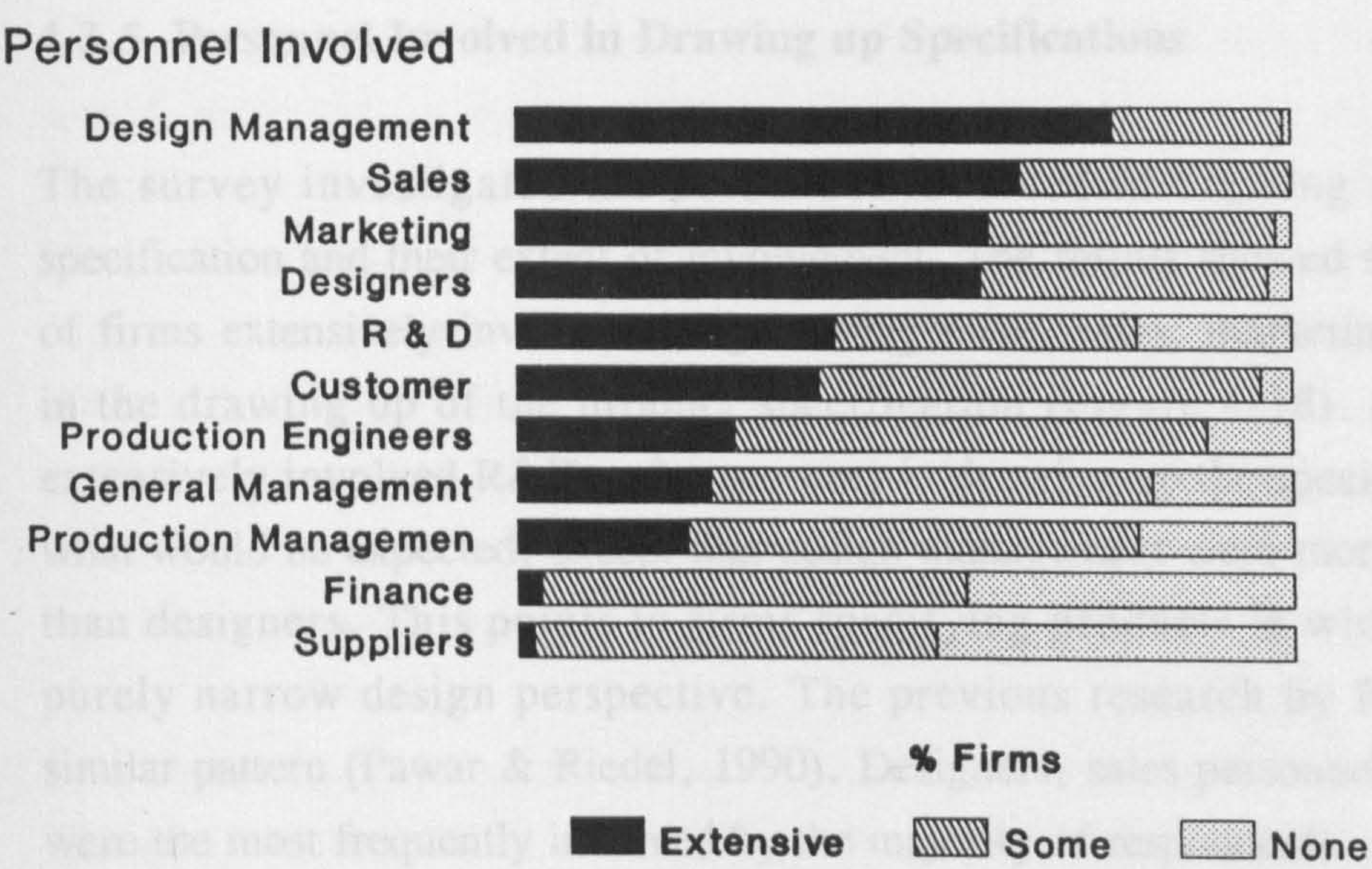


Fig 4-18 Specification Personnel Involve



4.3.4 Design Aspects Considered

The survey also investigated what aspects the product specification drawn up by firms actually covered. The results showed that functional requirements was overwhelmingly the aspect considered by most firms in their specifications (see Figure 4-17). Engineering design and product cost were the next most frequent aspects considered. This result was confirmed in the analysis of the most important aspect. This showed functional requirements were judged the most important aspect by two thirds of the firms answering the question. Engineering design and product cost were considered the most important aspect by only 16 and 11% of firms responding to the question respectively. A majority of firms considered project duration and compatibility with existing products in the specification. Materials and standardisation were considered by a half of firms. A third of firms considered development costs and styling/ appearance in the specification. Importantly, fewer than a quarter of firms considered production aspects in the specification (labour requirements, assembly techniques and production processes). It can be concluded that the most important aspects that firms considered in their product specifications were functional and engineering requirements along with product cost. Fewer than a quarter of firms considered production aspects in the specification. Thus the pulling forward of the design process, recommended by Hollins & Pugh (1990), was not detected by the survey. Only a small minority of firms considered the later, production aspects, in the early phase of compiling the product specification.

4.3.5 Personnel Involved in Drawing up Specifications

The survey investigated the personnel involved in drawing up the product specification and their extent of involvement. The results showed that the majority of firms extensively involved design management, sales, marketing and designers in the drawing up of the product specification (Figure 4-18). A half of firms extensively involved R&D and customers in drawing up the specification. This is what would be expected, except that design management were more often involved than designers. This points to firms specifying products in wider terms than a purely narrow design perspective. The previous research by Pawar showed a similar pattern (Pawar & Riedel, 1990). Designers, sales personnel, and customers were the most frequently involved by the majority of respondents.

Again, however, fewer than a third of firms extensively involved production engineering personnel and production management in drawing up specifications. Just under a half of firms did not involve finance and suppliers in the drawing up of the product specification. Hence, it can be concluded that the expertise and knowledge of production personnel are not included in the product specifications drawn up by companies.

4.3.6 Conclusion

This section has considered the characteristics of mechanical engineering firms who compiled product specifications. It was found that the majority of firms drew up a product specification. In terms of regional distribution the analysis showed that regional location did not influence firms in compiling specifications. Firms with more than 50 establishment employees compiled product specifications, firms smaller than this were less likely to. Subcontracting was confined to firms with less than 200 establishment employees. The overwhelming majority of firms with sales turnovers over £2 million drew up specifications. The smaller firms tended to supplement written specifications with verbal instructions, 15% using verbal only specifications. There was a mild tendency for no specification to be drawn up as production equipment age rose to 30 years old. The process technology used by firms did not determine specification compilation, although, a third of one-off producers did not have specifications. The type of product (final, intermediate, both or consumer) was found not to influence product specification compilation. The number of new products a firm introduced per year did not influence the use of product specifications. The majority of firms compiled a written product specification (55%). Forty two per cent of firms used verbal and written product specifications. Only three per cent of firms used a verbal specification. Establishment size only influenced the compilation of product specifications in the case of small and very small establishments where verbal specifications became more prominent. Firms with new production equipment used only written specifications, there was no difference for firms with older equipment. Process technology did not determine which format of specification was used, except in the case of mass production.

Two measures of design effectiveness were used to determine firms' performance. The analysis of the first, standardisation, produced ambiguous results. Do firms with written specifications (as opposed to both written and verbal) have higher standardisation, or do firms with higher standardisation find it easier to have written only specifications? The survey data, unfortunately, do not allow this question to be resolved. It is hoped to resolve this issue in a series of structured interviews. These are discussed in chapters 5 and 6 of the thesis. The other measure of design effectiveness was modification. At higher levels of modification it is better to supplement written product specifications with verbal instructions to reduce the amount of modification. At low levels of modification it is slightly better not to supplement written specifications.

The most important aspects that firms considered in their product specifications were functional and engineering requirements along with product cost. Fewer than a quarter of firms considered production aspects in the specification. Thus the pulling forward of the design process was not detected by the survey. Only a small minority of firms considered the later, production aspects, in the early phase of compiling the product specification. The majority of firms extensively involved design management, sales, marketing and designers in the drawing up of the product specification. The priority accorded to the involvement of design management points to firms specifying products in wider terms than a purely narrow design or sales perspective. However, the expertise and knowledge of production personnel are not included in the product specifications drawn up by companies.

This section has presented the analysis of product specification use, format, content (aspects considered), personnel compiling and the characteristics of firms using them for the UK mechanical engineering industry. It has also examined the impact of the product specification upon the product design effectiveness of companies. The next section analyses the organisational arrangements for product design and their impact upon design effectiveness.

4.4 Organisation & Co-ordination

This section deals with the second theme, organisation and co-ordination of design within companies. It presents the findings regarding organisational structures, co-ordinating mechanisms and personnel used by companies in designing new products. It also presents the factors influencing the use of these and the analysis of design performance.

4.4.1 Design and Organisation Structure

The results for organisational structure are presented in Figure 4-19. Simultaneous engineering was the most frequently used organisational structure, 40% of firms using it. Matrix organisation and integrated Product-Process design departments were equally used by a quarter of firms. The four percent of firms not using a structure were very small firms (less than 50 employees). It must be said that the 40% for simultaneous engineering is a little higher than expected and requires some explanation. This can only be resolved by further questioning of the respondent firms. At the time of the formulation of the structured interviews it was decided not to investigate this further.

The factors influencing the use of different structures were broken down into: establishment employees, turnover and production equipment age. As would be expected the more complex and people-intensive matrix organisation structure had a tendency to be used by larger firms (Figure 4-20). Also fitting in with expectations was the trend of integrated product-process design departments to be used as organisations got smaller. A significant proportion of medium sized firms also used integrated departments. Simultaneous engineering was almost evenly distributed across the size range, falling off only in the larger firms above 500 employees. Turnover showed a similar effect with matrix organisation being used by larger organisations (Figure 4-21). Integrated product-process design departments were used more by firms in the two to ten million pound range, ie. small firms. Production equipment age only showed the effect of tending to reduce use of simultaneous engineering for equipment ages in the middle range, of 6 to 10 years (Figure 4-22).

Fig 4-19 Organisation Structure

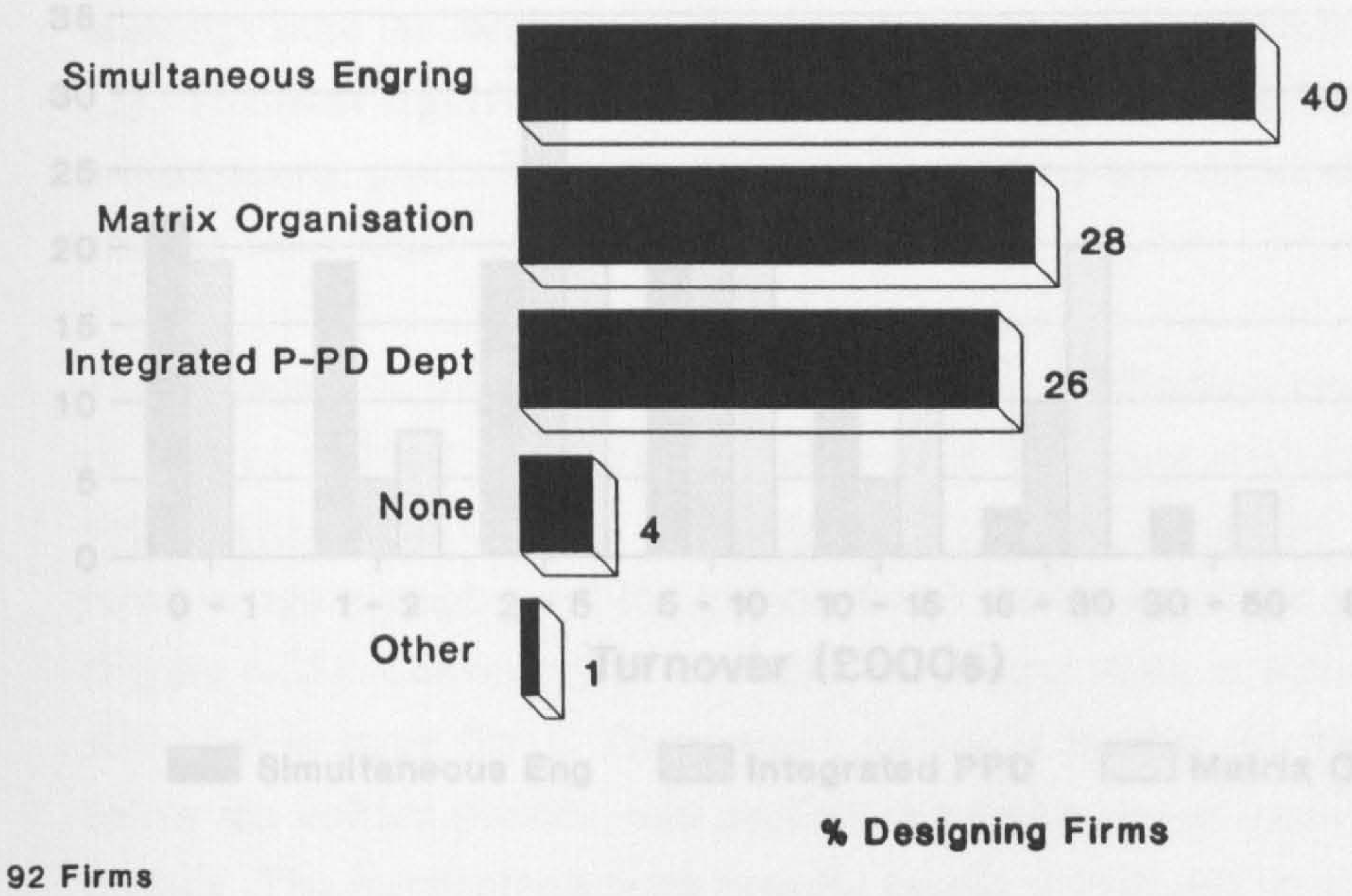


Fig 4-20 Structure & Employees

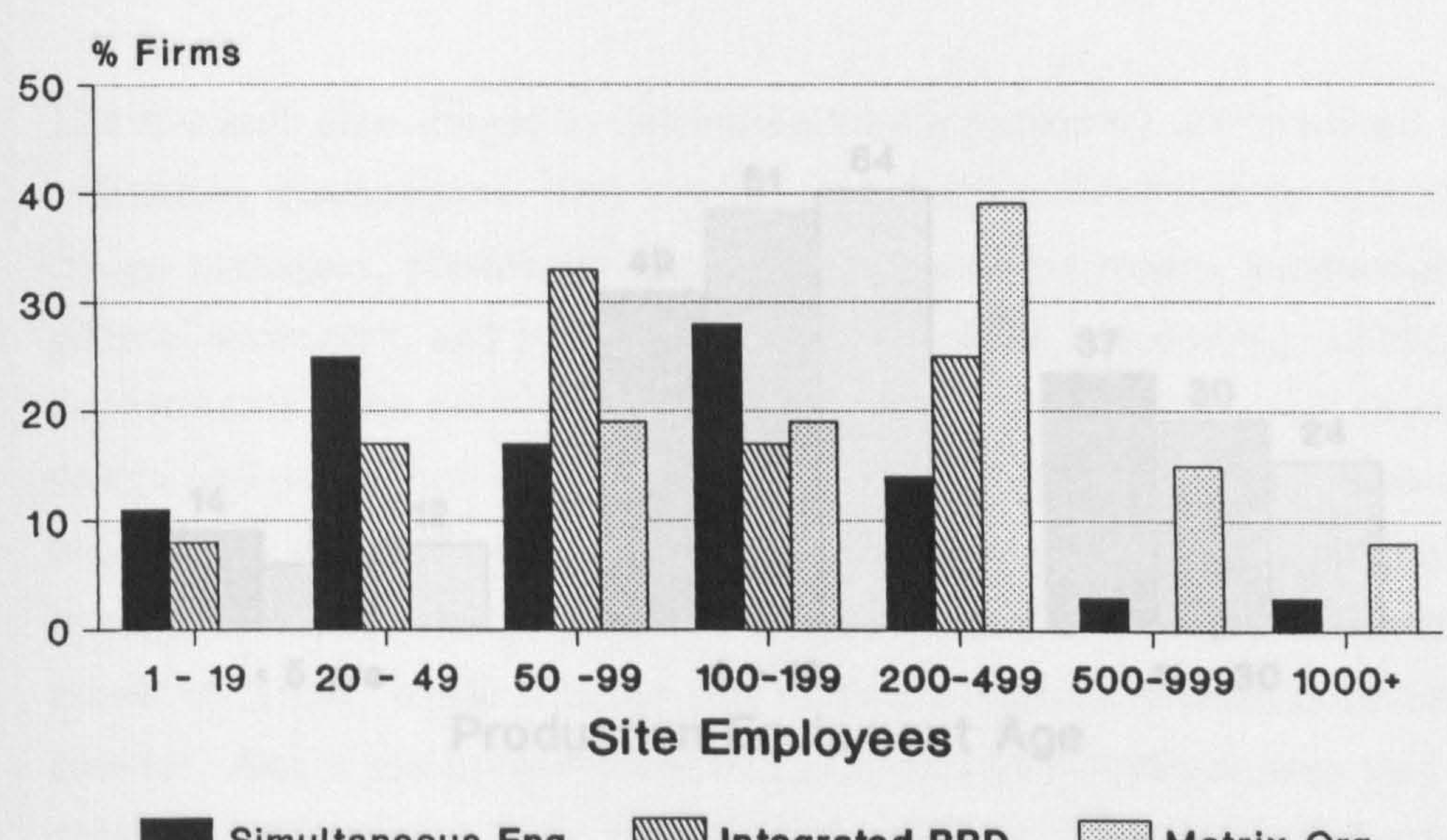


Fig 4-21 Structure & Sales Turnover

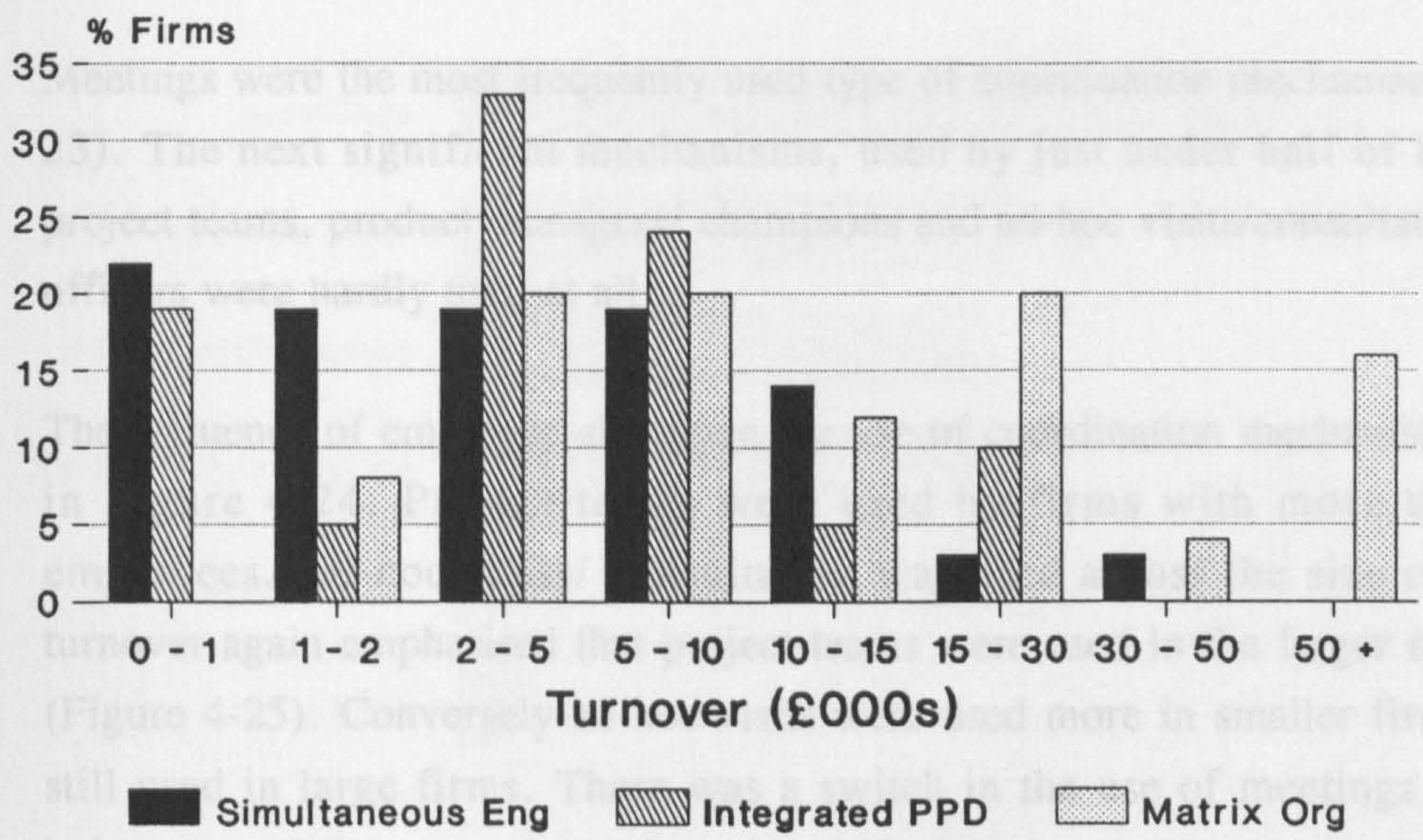
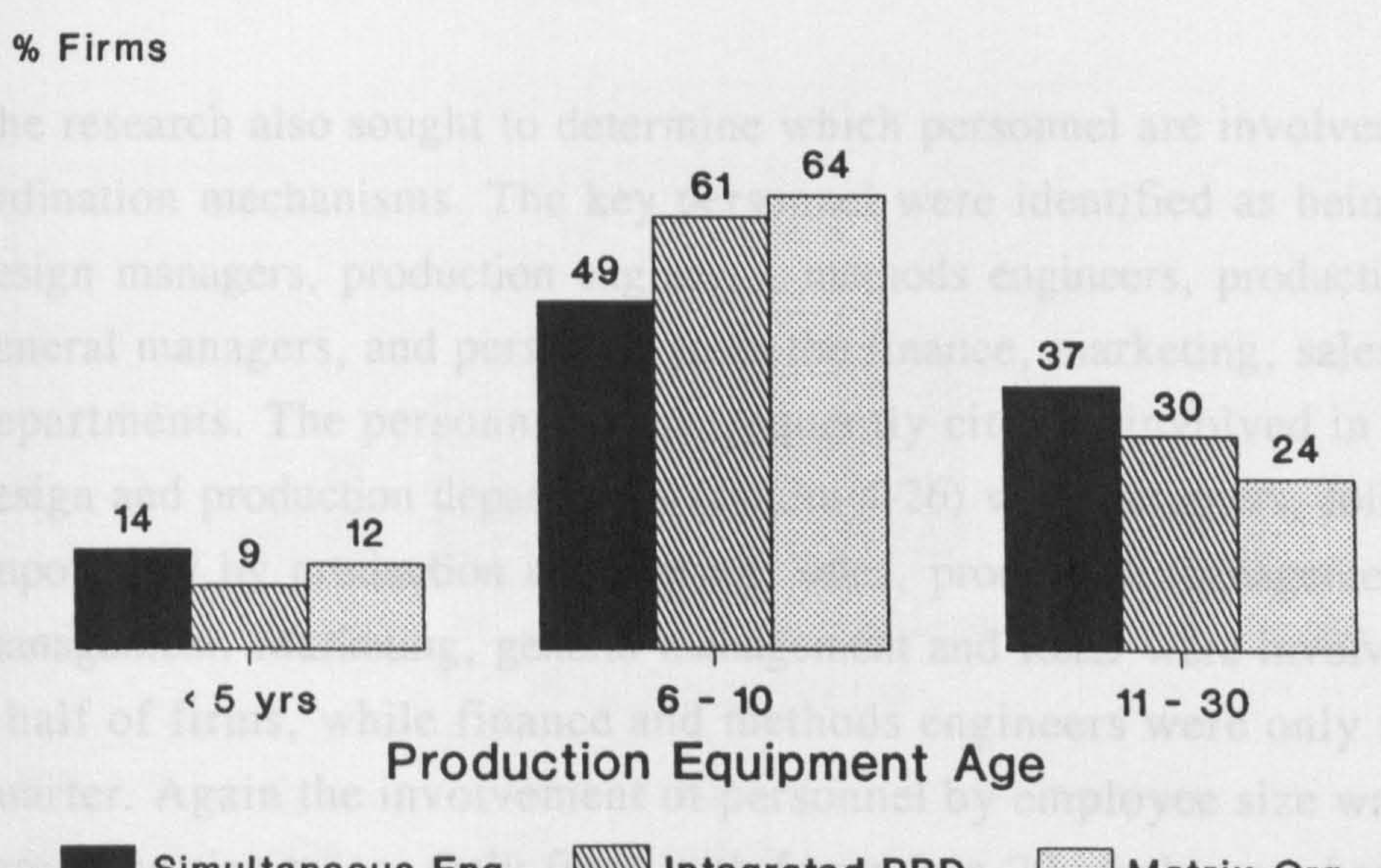


Fig 4-22 Structure & Prodn Equip Age



4.4.2 Co-ordination Mechanisms

Although a formal organisational structure may be in place for design and production there is still the issue of the management and co-ordination of design activities. The following mechanisms of co-ordinating design were identified: project team, product manager/ champion, meetings, ad hoc visits/ consultation and liaison officers.

Meetings were the most frequently used type of coordination mechanism (Figure 4-23). The next significant mechanisms, used by just under half of firms, were project teams, product managers/ champions and ad-hoc visits/consultation. Liaison officers were hardly used at all.

The influence of employee size upon the use of coordination mechanisms is shown in Figure 4-24. Project teams were used by firms with more than twenty employees. Ad-hoc visits/ consultation was used across the size range. Sales turnover again emphasised that project teams were used in the larger organisations (Figure 4-25). Conversely ad-hoc visits were used more in smaller firms but were still used in large firms. There was a switch in the use of meetings, used more below ten million pounds, and product champions, used more above ten million pounds. The mechanisms were broadly evenly distributed so general conclusions were difficult to draw.

4.4.3 Co-ordination Personnel

The research also sought to determine which personnel are involved in these co-ordination mechanisms. The key personnel were identified as being: designers, design managers, production engineers, methods engineers, production managers, general managers, and personnel from the finance, marketing, sales, and R & D departments. The personnel most frequently cited as involved in coordinating design and production departments (Figure 4-26) were designers, followed equally importantly by production engineering, sales, production management and design management. Marketing, general management and R&D were involved in roughly a half of firms, while finance and methods engineers were only involved in a quarter. Again the involvement of personnel by employee size was fairly even across the size range. Only firms with fewer than 20 employees showed a marked lack of personnel involvement - as would be expected.

Fig 4-23 Design Co-ordination Mechanisms

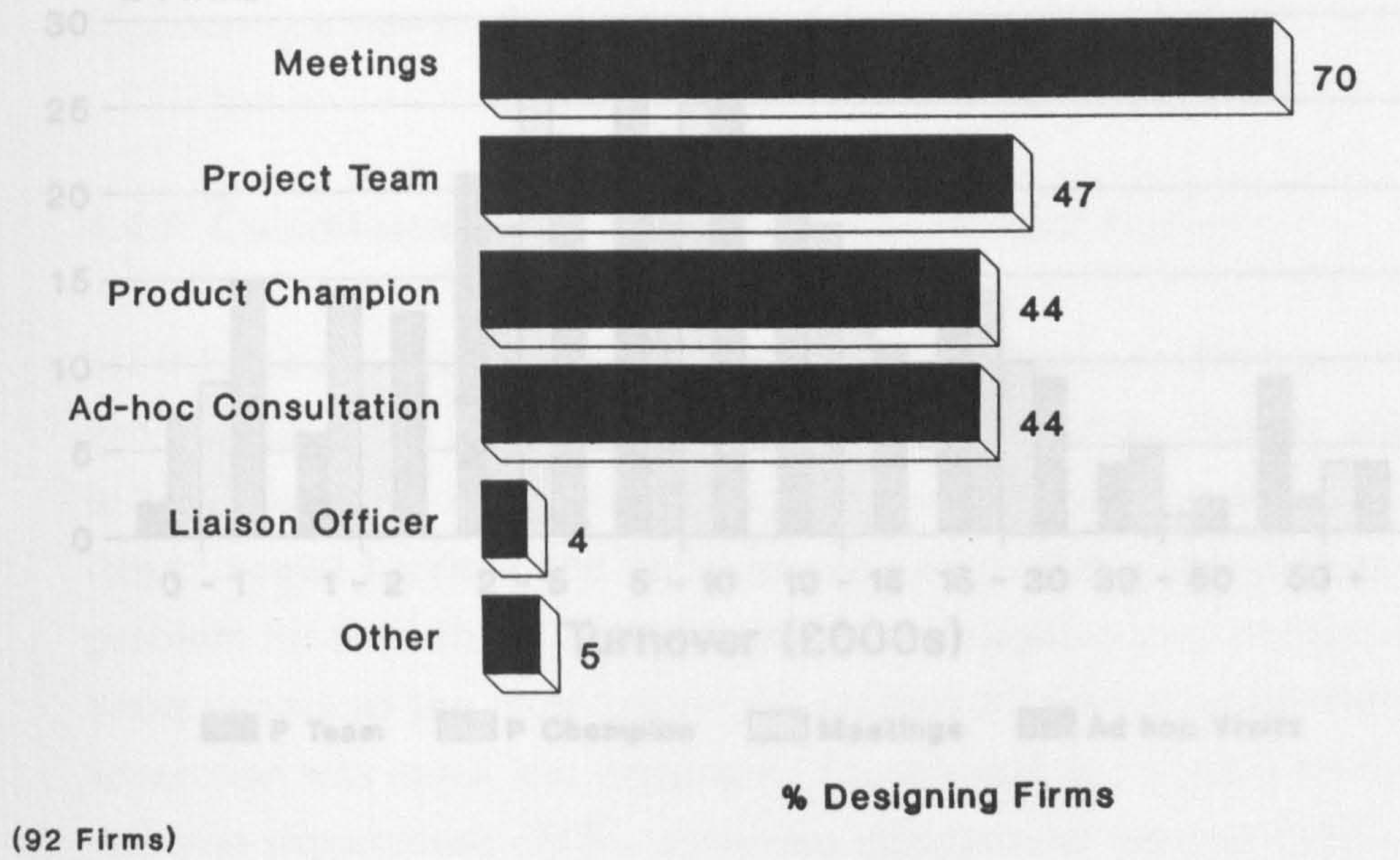


Fig 4-24 Co-ord Mechanisms & Size

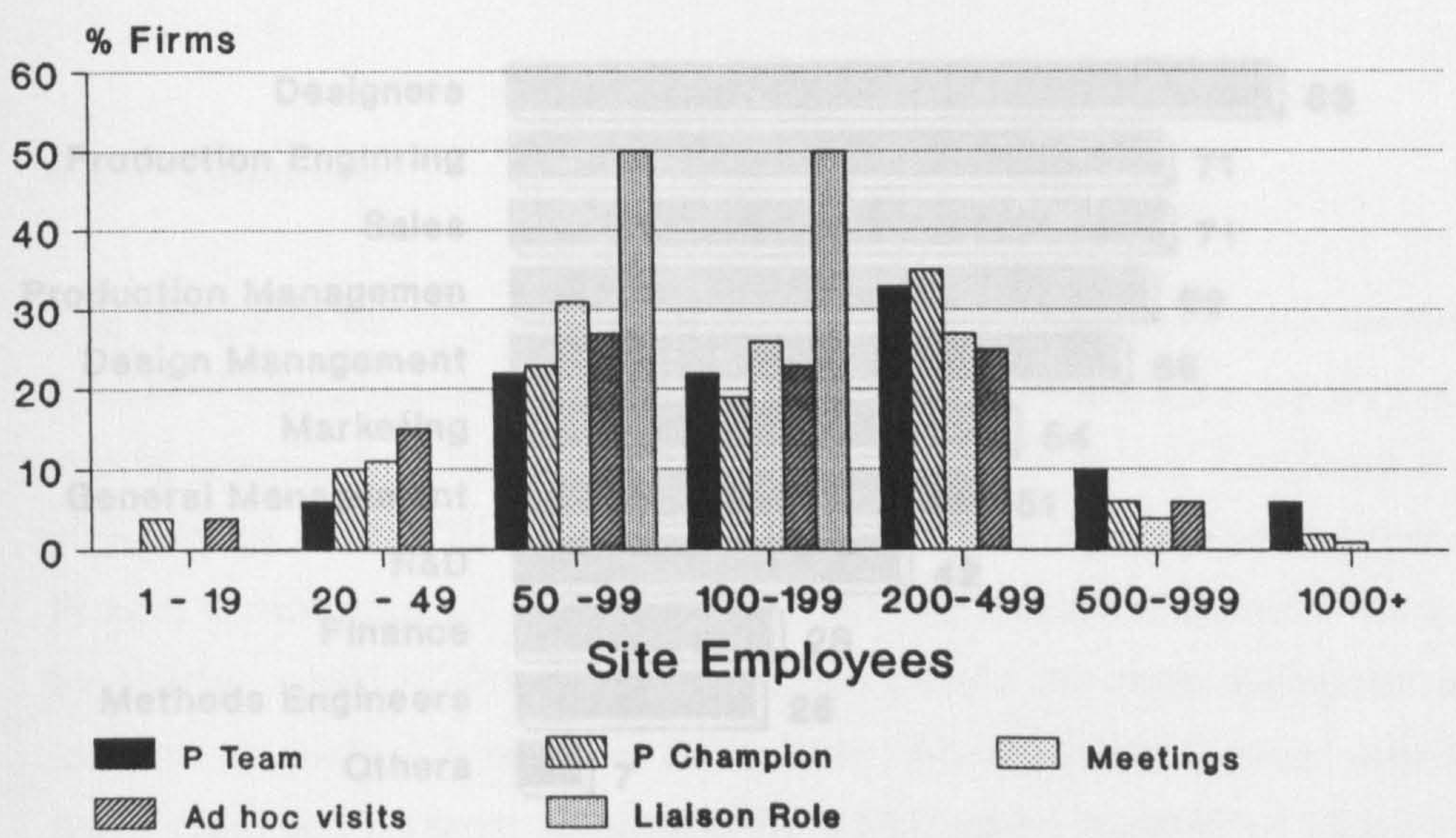


Fig 4-25 Co-ord Mechanism & Sales Turno

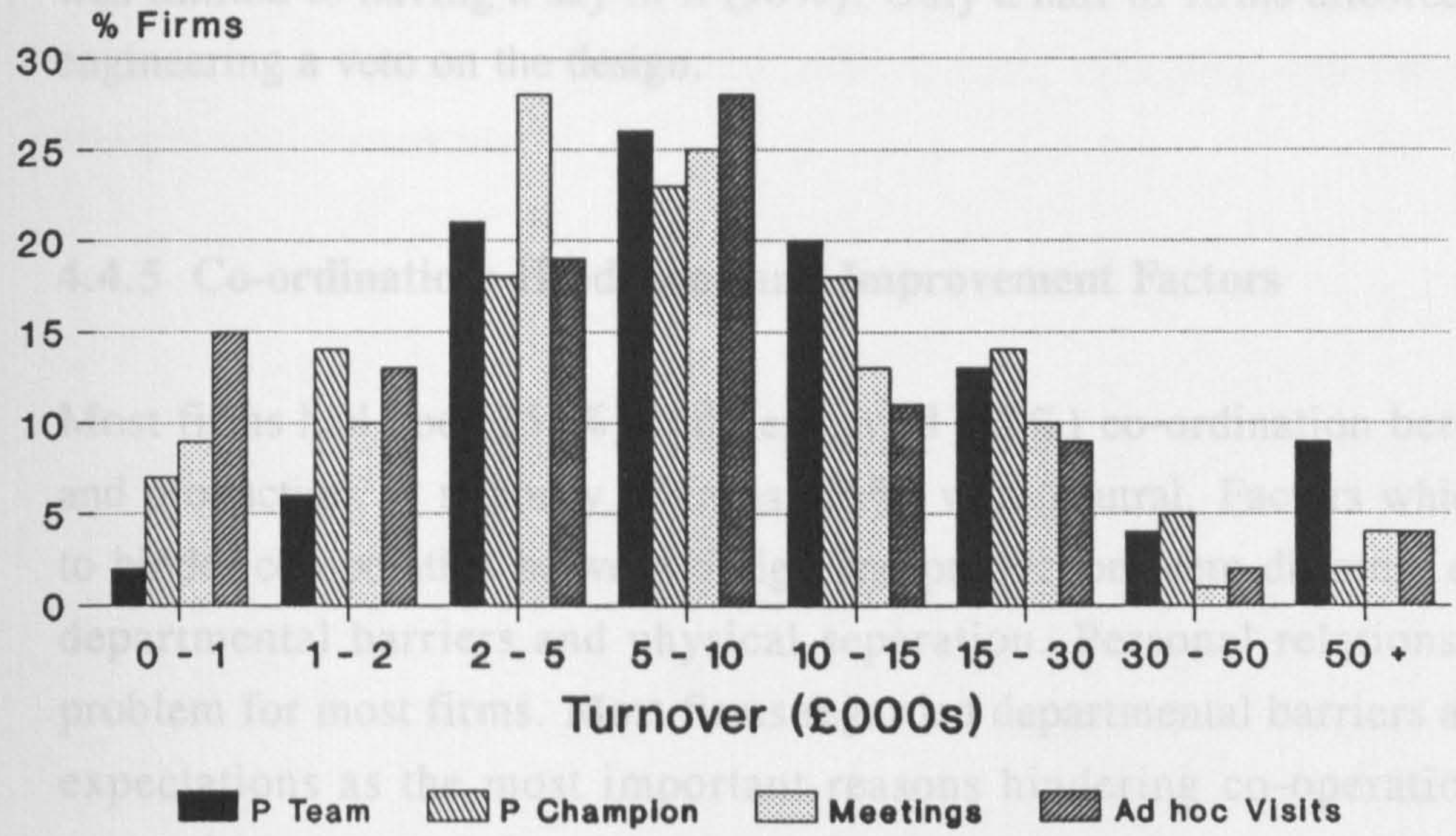
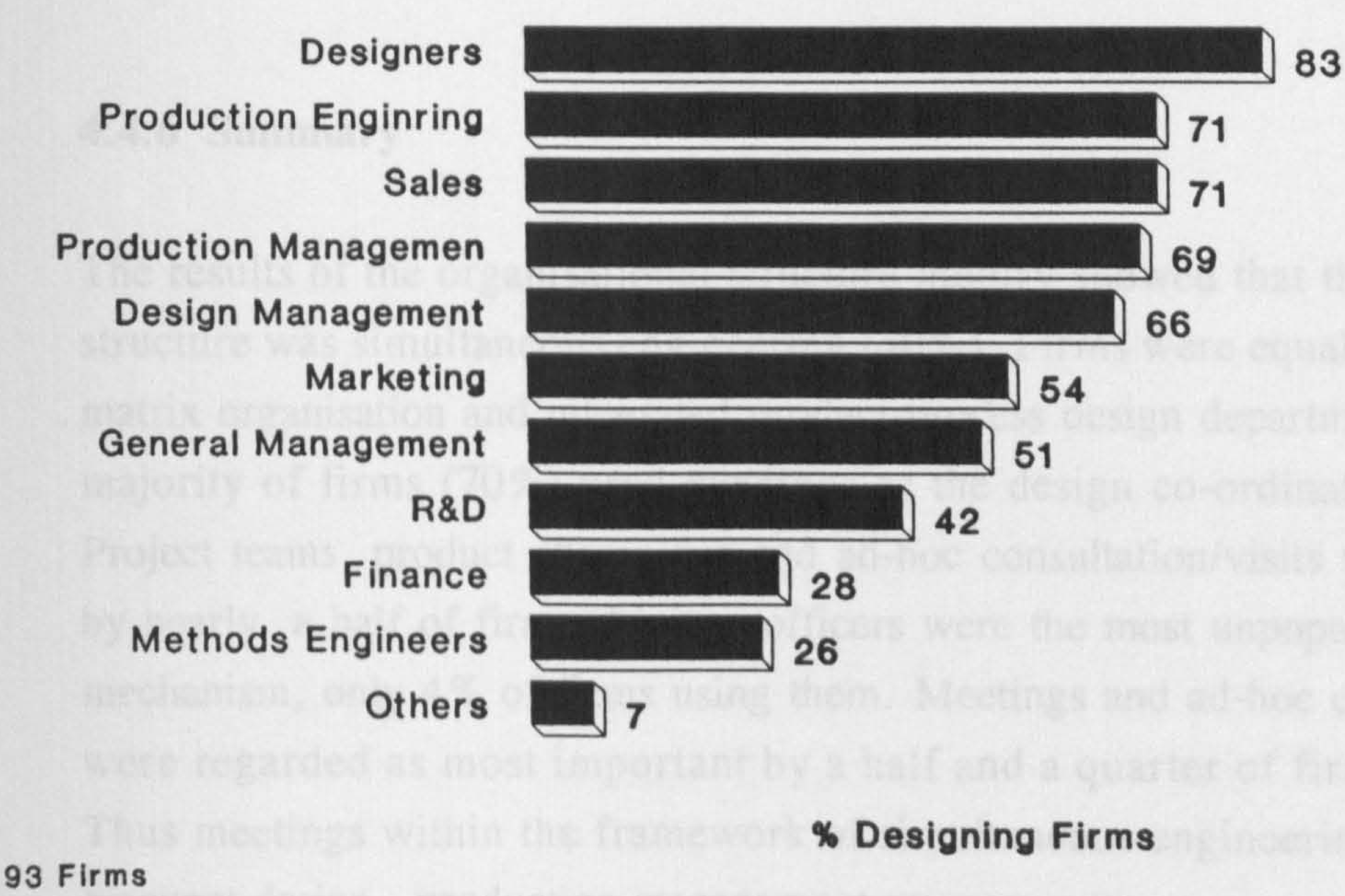


Fig 4-26 Design Co-ordination Personnel



4.4.4 Design Control

An additional refinement of design management is the holding of design reviews. These are conducted by senior management and consist of the review of the progress of the products currently being designed. The majority of firms used design reviews, but only a half had design freezes and design procedures. Production engineering involvement in the design, in the majority of companies, was limited to having a say in it (90%). Only a half of firms allowed production engineering a veto on the design.

4.4.5 Co-ordination: Hindrance and Improvement Factors

Most firms had good (51%) and very good (22%) co-ordination between design and production. A minority of firms (26%) were neutral. Factors which were said to hinder co-operation between design and production were different expectations, departmental barriers and physical separation. Personal relations were not a problem for most firms. Most firms regarded departmental barriers and differing expectations as the most important reasons hindering co-operation. Physical separation was much less important. Factors said to improve co-operation were common expectations (34%), removing departmental barriers (31%) and physical closeness (19%). This analysis implies that the differentiation between design and production departments had created a management problem for firms. Thus, management were still trying to understand the interface between design and production and how to manage it.

4.4.6 Summary

The results of the organisational structure inquiry showed that the most frequent structure was simultaneous engineering (40%). Firms were equally split in use of matrix organisation and integrated product-process design departments (27%). The majority of firms (70%) used meetings as the design co-ordination mechanism. Project teams, product champions and ad-hoc consultation/visits were each in use by nearly a half of firms. Liaison officers were the most unpopular co-ordination mechanism, only 4% of firms using them. Meetings and ad-hoc consultation/visits were regarded as most important by a half and a quarter of firms respectively. Thus meetings within the framework of simultaneous engineering were the most frequent design - production management arrangements.

Designers, sales, production engineering, production management and design management were the personnel most heavily involved in design - production co-ordination. Involvement was not significantly influenced by establishment size.

Design reviews were held by most firms. Production engineering involvement was limited to only having a say in the design. Most firms, however, had good co-ordination between design and production. Factors which hindered co-operation were different expectations, departmental barriers and physical separation. Improvement factors were common expectations, removing departmental barriers and physical closeness.

Fig 4-27 Structure & Modification

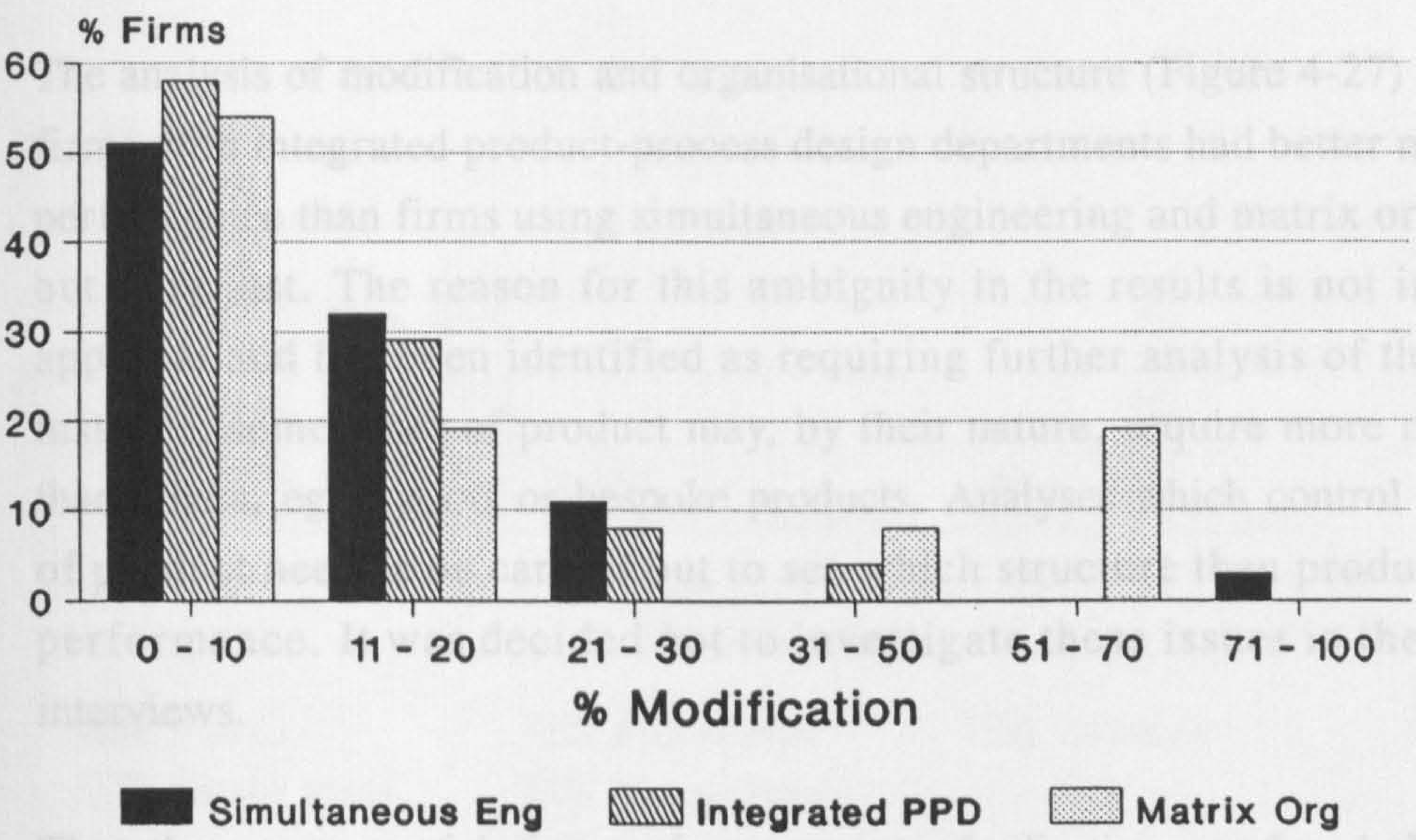
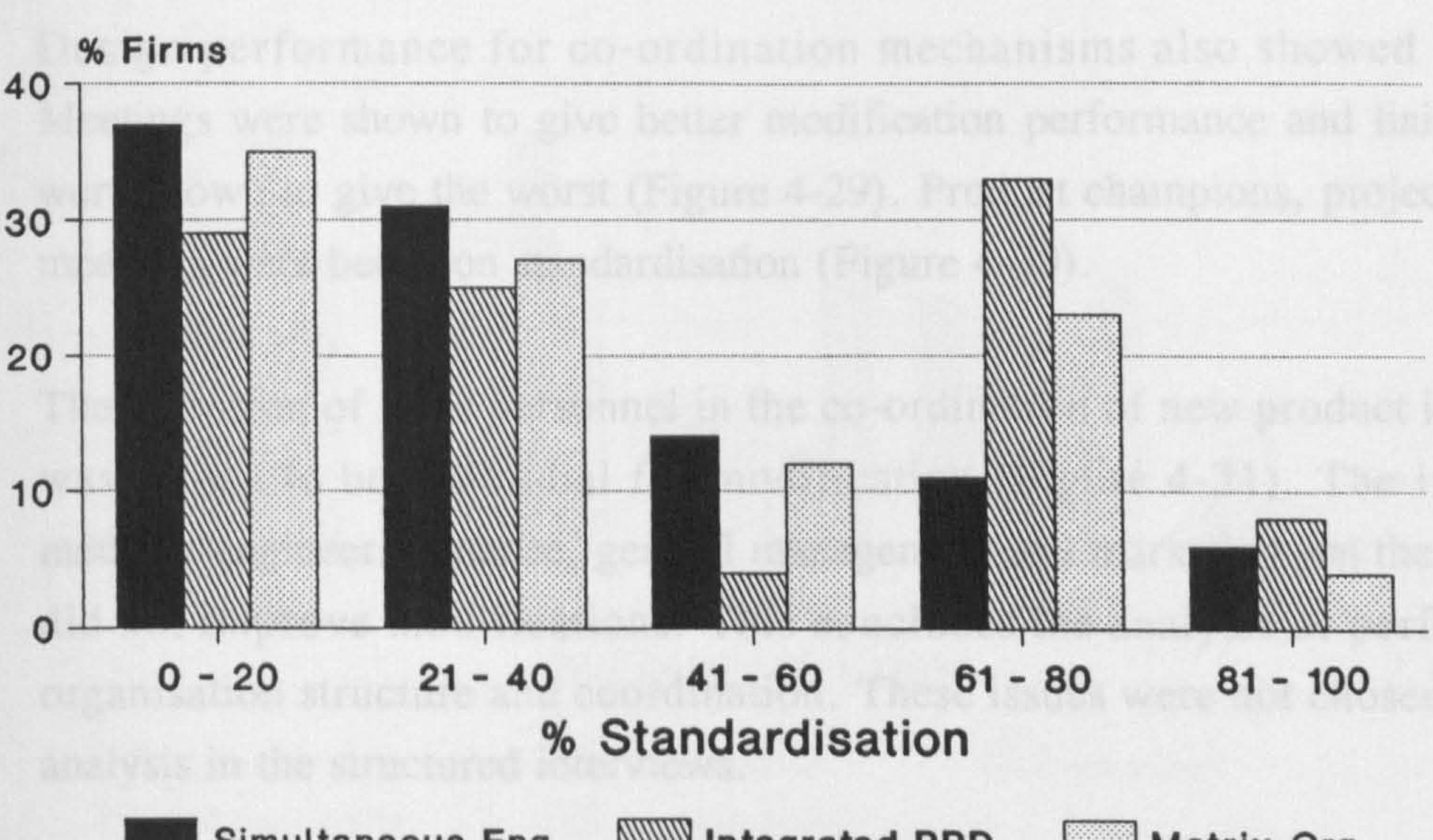


Fig 4-28 Structure & Standardisation



4.4.7 Organisation & Co-ordination & Design Performance

The analysis proceeded to attempt to deduce which type of organisational arrangement produced better designs. The measures of design performance were the percent of components modified after drawings had been transferred to production (modification) and the number of standard components used in designs (standardisation).

The analysis of modification and organisational structure (Figure 4-27) showed that firms with integrated product-process design departments had better modification performance than firms using simultaneous engineering and matrix organisation - but only just. The reason for this ambiguity in the results is not immediately apparent and has been identified as requiring further analysis of the data. For instance, some types of product may, by their nature, require more modification than others, eg. one-off or bespoke products. Analyses which control for the type of product need to be carried out to see which structure then produces the best performance. It was decided not to investigate these issues in the structured interviews.

The other measure of design performance, standardisation, produced clearer results (Figure 4-28). It showed that integrated product-process design departments produced higher levels of standardisation than other structures. Simultaneous engineering was shown to be a worse performer on standardisation than matrix organisation.

Design performance for co-ordination mechanisms also showed ambiguity. Meetings were shown to give better modification performance and liaison officers were shown to give the worst (Figure 4-29). Product champions, project teams and meetings were better on standardisation (Figure 4-30).

The inclusion of sales personnel in the co-ordination of new product introduction was shown to be beneficial for modification (Figure 4-31). The inclusion of methods engineers, finance, general management and marketing, on the other hand, did not improve modifications. This concludes the analysis of performance of organisation structure and coordination. These issues were not chosen for further analysis in the structured interviews.

Fig 4-29 Co-ord Mechanism & Modificatio

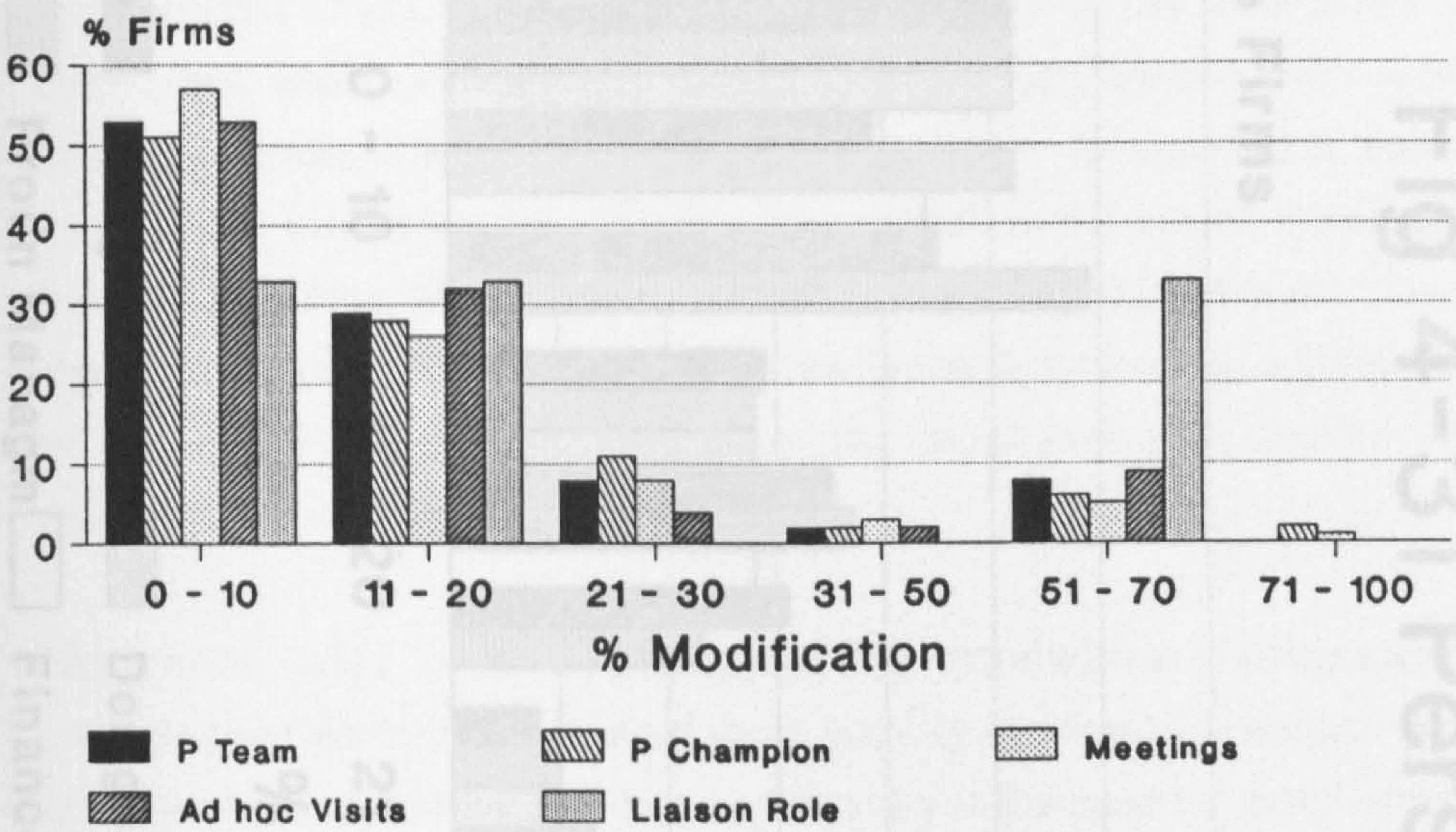


Fig 4-30 Co-ord Mechanism & Standardisa

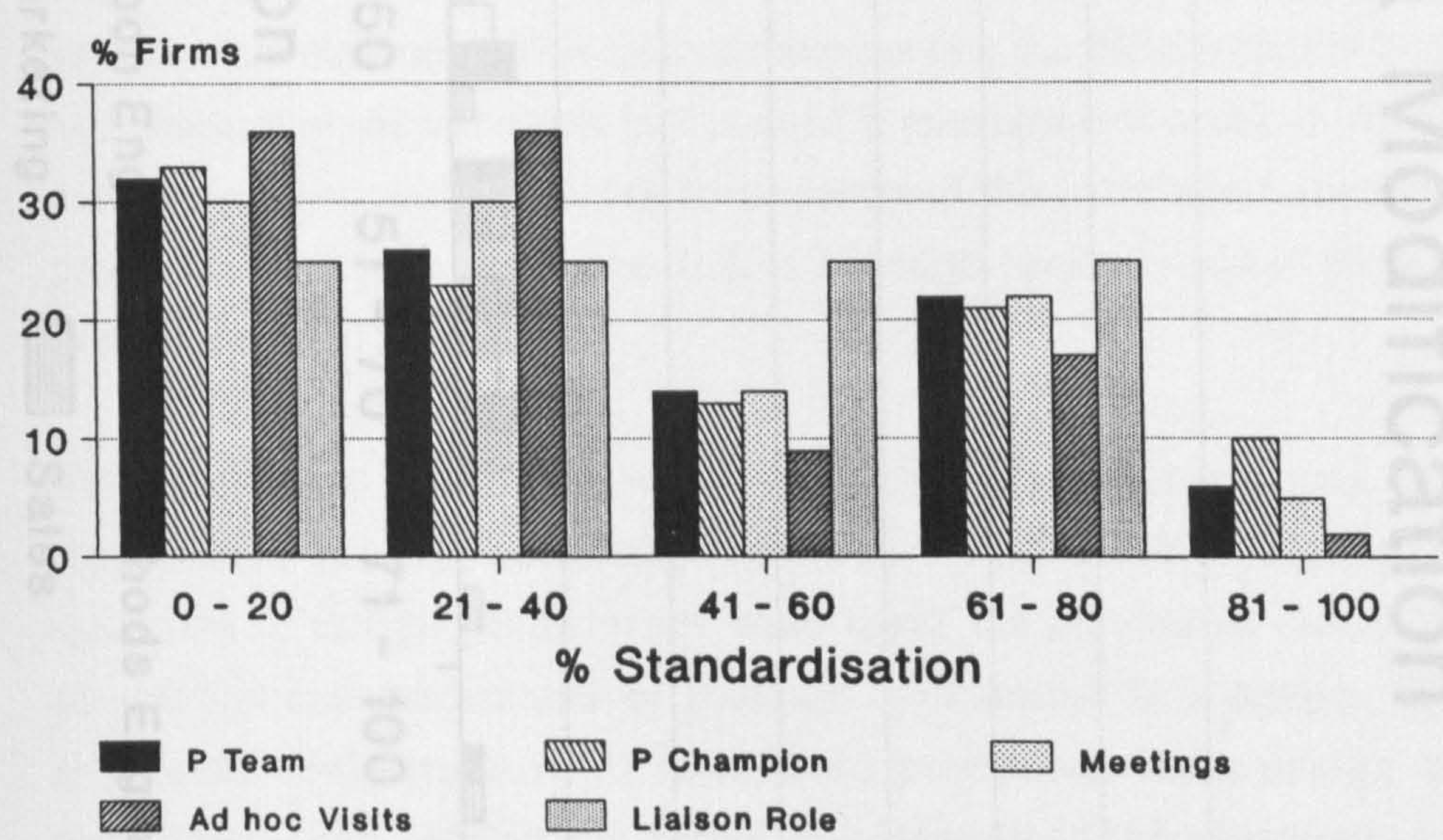
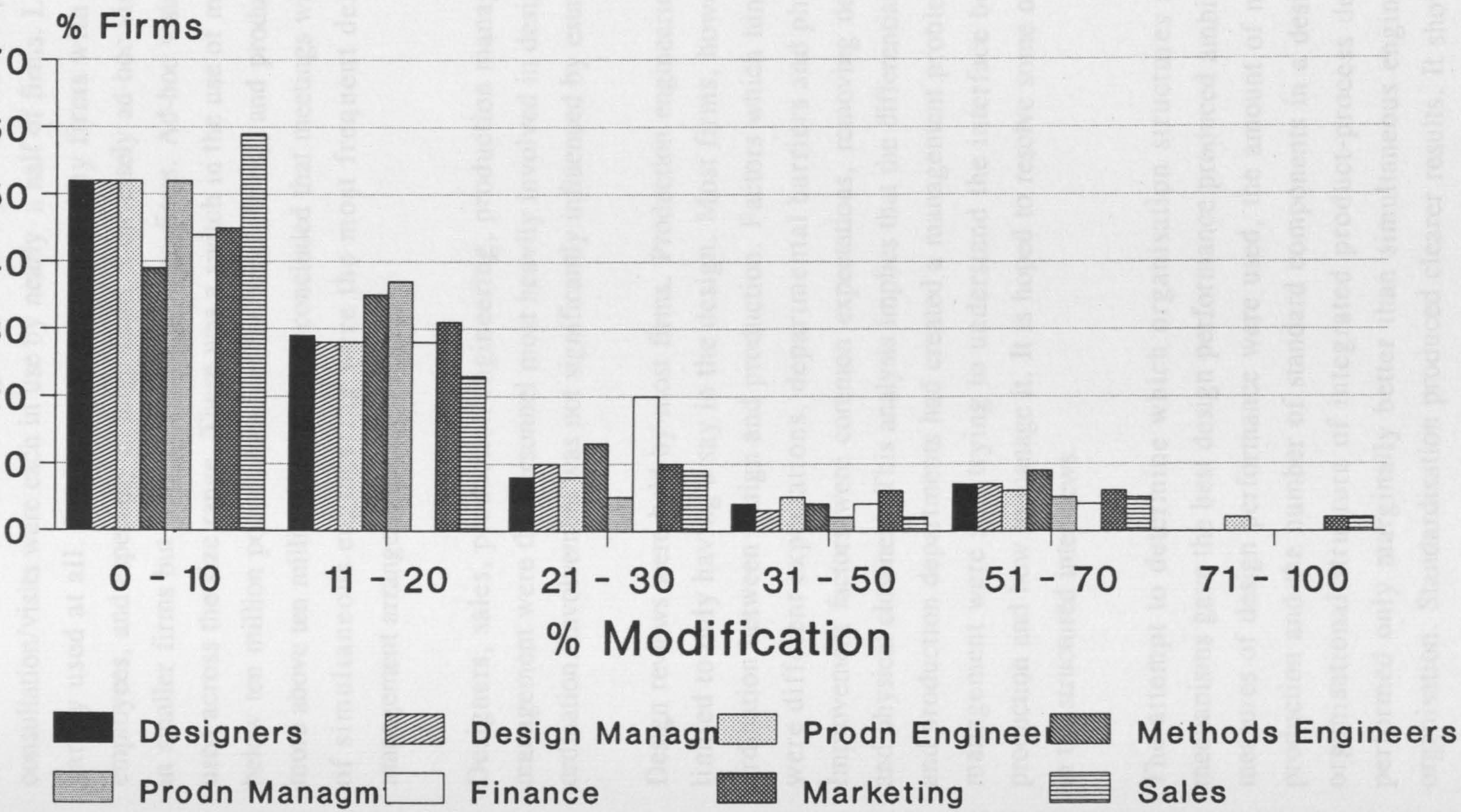


Fig 4-31 Personnel & Modification



4.4.8 Organisation & Co-ordination: Summary

The most frequent organisation structure was simultaneous engineering. Firms were equally split in the use of matrix organisation and integrated product-process design departments. The majority of firms used meetings as the design co-ordination mechanism. Project teams, product champions and ad-hoc consultation/visits were each in use by nearly a half of firms. Liaison officers were hardly used at all. Project teams were used by firms with more than twenty employees, and especially in large firms. Conversely ad-hoc visits were used more in smaller firms but were still used in large firms. Ad-hoc visits/ consultation was used across the size range. There was a switch in the use of meetings, used more below ten million pounds turnover (ie. small firms), and product champions, used more above ten million pounds. It is concluded that meetings within the framework of simultaneous engineering were the most frequent design - production management arrangements.

Designers, sales, production engineering, production management and design management were the personnel most heavily involved in design - production co-ordination. Involvement was not significantly influenced by establishment size.

Design reviews were held by most firms. Production engineering involvement was limited to only having a say in the design. Most firms, however, had good co-ordination between design and production. Factors which hindered co-operation were different expectations, departmental barriers and physical separation. Improvement factors were common expectations, removing departmental barriers and physical closeness. This analysis implies that the differentiation between design and production departments had created a management problem for firms. Thus, management were still trying to understand the interface between design and production and how to manage it. It is hoped to resolve some of these conundrums in the structured interviews.

The attempt to determine which organisation structures and co-ordination mechanisms gave the best design performance produced ambiguous results. Two measures of design performance were used, the amount of modification during production and the number of standard components in a design. Firms with an organisational structure of integrated product-process design departments performed only marginally better than simultaneous engineering and matrix organisation. Standardisation produced clearer results. It showed that integrated product-process design departments produced higher levels of standardisation than other structures. Simultaneous engineering was shown to be a worse performer on standardisation than matrix organisation. The co-ordination mechanisms of meetings, product champions and project teams again gave only slightly better results. The inclusion of sales personnel was shown to increase firms' performance, whereas marketing did not. This lack of clarity in the survey results could be subject to further analysis and investigation. However, this was not possible in this research.

4.5 The Consideration of Production

This section presents the results of the analysis of the consideration of production aspects by firms during the product design process. It shows which aspects of production were considered in the design of products and, more importantly, shows when companies considered which production aspects during the design of products.

The consideration of production was broken down into two items: first the consideration paid to production aspects during different stages of the design process; second the involvement of production engineering personnel and the influence of these personnel in terms of a veto over the design. The first part of the section presents the results of the analyses of each of these items. The second part presents the results of the analysis of how consideration of production influenced the design performance of companies.

4.5.1 Design Stages & Production Aspects

The section considers the issue of which aspects of production should be considered in the design of products. More importantly, it shows when companies considered which production aspects during the design of products. The consensus in the literature is that the early consideration of the manufacture of a product during its design is both beneficial to the design and also to manufacture. Specifically, the design can be tailored to allow the more effective (ease of assembly, use of previous designs) and efficient manufacture (cost, time, use of standard components) of the product. The research set out to investigate whether or not companies actually considered production early during the design of products.

The survey also examined which design aspects were considered, this was done to allow the consideration of production aspects to be compared against them. The design aspects investigated were: product costs, development costs, functional requirements, engineering design and styling/ appearance. The production aspects determined to be of significance and investigated in the research were: standardisation, production processes, plant, machinery, assembly techniques, labour requirements, materials, existing products and production control.

Fig 4-32 Design Stages & Aspects Considered

These aspects were chosen after an extensive review of the literature on design and production aspects and the limitations of the survey questionnaire. The consideration of these aspects during the different phases of the design process was the first research question. The design process was broken down into the following stages: conception, detailed design, prototype/ testing, pre-production and production.

Before presenting the detailed breakdown of the results for each design stage some overall observations can be made. Figure 4-32 shows design aspects by design stage. During the conception stage of design the most important aspects were product cost, development costs, functional requirements, and materials. During detailed design the important aspects were engineering design, styling, standardisation, materials and to a lesser extent production processes. During the prototype stage the important aspects were production processes, plant machinery, assembly techniques and product quality. During pre-production the most important aspects were labour requirements and production control. Of lesser importance, but more so than during the prototype stage, were production processes, plant, machinery and assembly techniques. In the final design stage, production, the most important aspects were product quality, production control and labour requirements. The pattern of increasing consideration given to production aspects the closer the design stage moved to manufacture can be seen. This, of course, implies that the manufacturability of the product is not considered until after it has been designed. Thus, the effectiveness and efficiency of the manufacture of the product are not given adequate attention by the majority of mechanical engineering firms. This will impair firms' competitive performance. The following sections present the breakdown of the consideration of production aspects by design stage.

4.5.1.1 Conceptual Design Stage & Production Aspects

The first stage of the design process has been identified as the most crucial for the successful introduction of new products (Hollins & Pugh 1990, Pawar et.al. 1994). For instance, conceptual design has been shown to determine the overwhelming proportion of the cost of production of a product's design (Charney 1991). Therefore, the consideration of production aspects during conceptual design is most important in improving the efficiency of manufacture of designs. The implications of companies not considering production are enormous. Figure 4-33 presents the production aspects considered by companies during conceptual design. The most important aspects considered by firms were functional requirements, product cost, and development costs. These were design aspects and not production aspects. The only production aspects given any significant consideration by firms were existing products, materials, standardisation and product quality. All the other production aspects were given minimal consideration. It can be concluded that production techniques were not considered during conceptual design by the majority of mechanical engineering companies.

4.5.1.2 Detailed Design Stage & Production Aspects

Figure 4-34 shows the design aspects considered during the detailed design phase. In terms of design aspects engineering design was the most important, followed by styling and appearance. A shift had thus occurred from considering the requirements of a design to its practicalities (or from specification to design). Production aspects were now considered, but only standardisation, materials, production processes and assembly techniques. Actual production considerations, such as production control and labour requirements, were only considered by a small number of firms.

4.5.1.3 Prototyping/ Testing Stage & Production Aspects

In the prototype stage costs (Figure 4-35) again attained importance along with functional requirements. Engineering design was still a priority, styling and appearance slightly less so. Production aspects moved to the fore in this stage. Product quality, assembly techniques, production processes, plant and machinery were all very important. Standardisation and existing products had receded in importance. Production control and labour requirements were now given significant attention. Materials, in contrast to detailed design, was no longer an issue.

4.5.1.4 Pre-Production Stage & Production Aspects

During the pre-production stage production aspects dominated design aspects, Figure 4-36. Production control and labour requirements had moved to be most important, followed by machinery, plant, production processes, assembly techniques and product quality.

Fig 4-33 Conception Stage & Des. Aspects

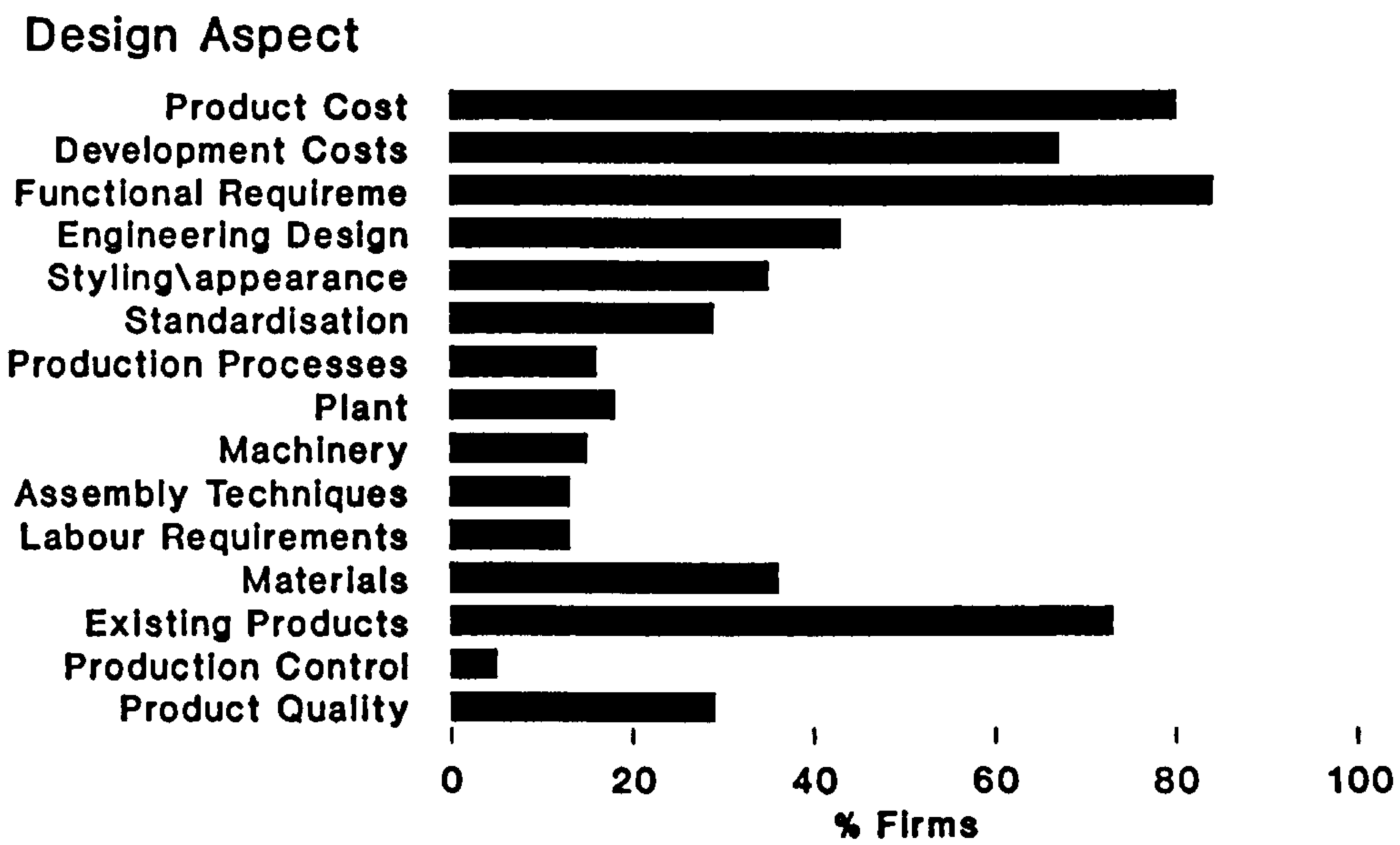


Fig 4-34 Detailed Design Stage & Aspects

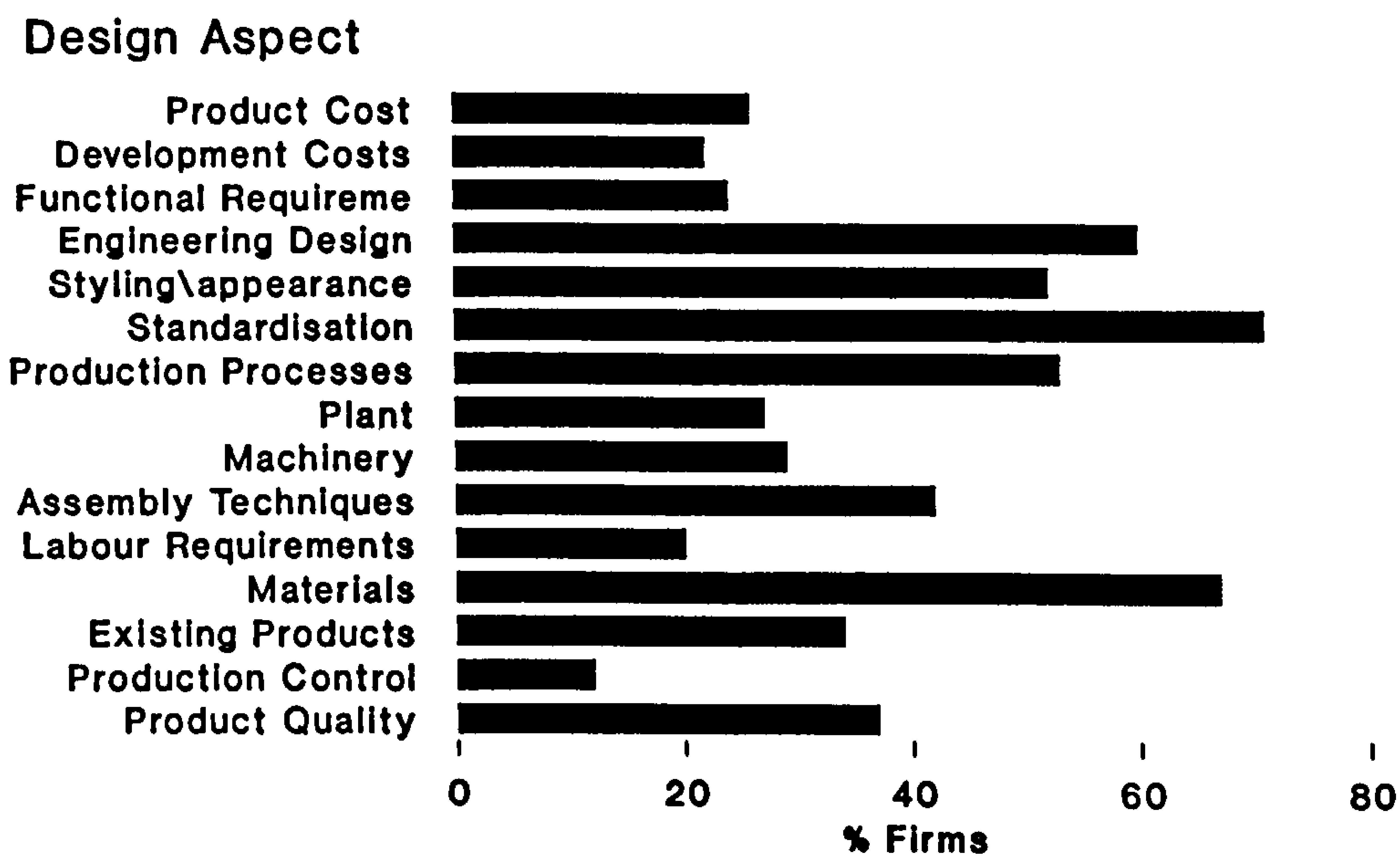


Fig 4-35 Prototype Stage & Design Aspect

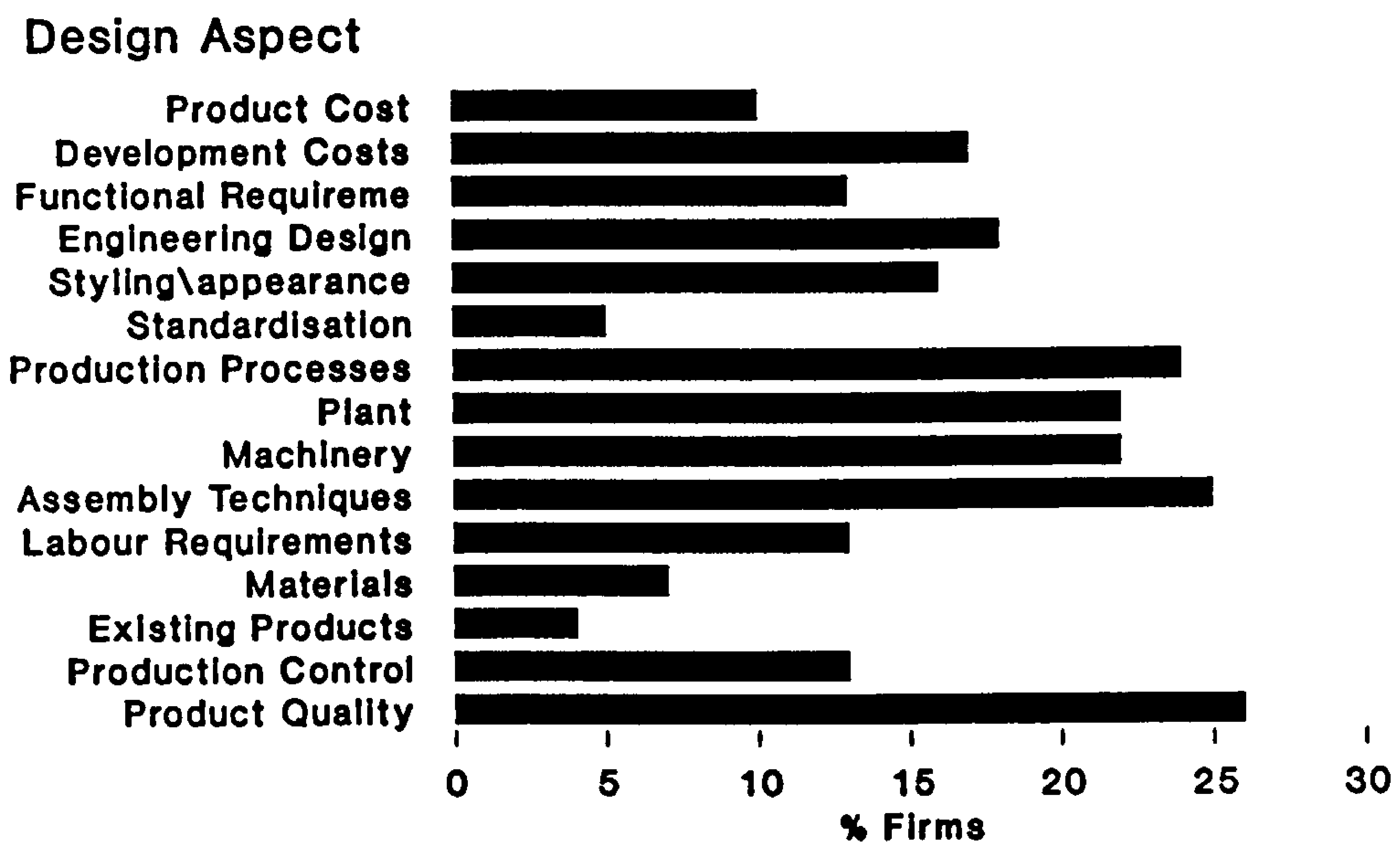


Fig 4-36 Pre-Production & Design Aspects

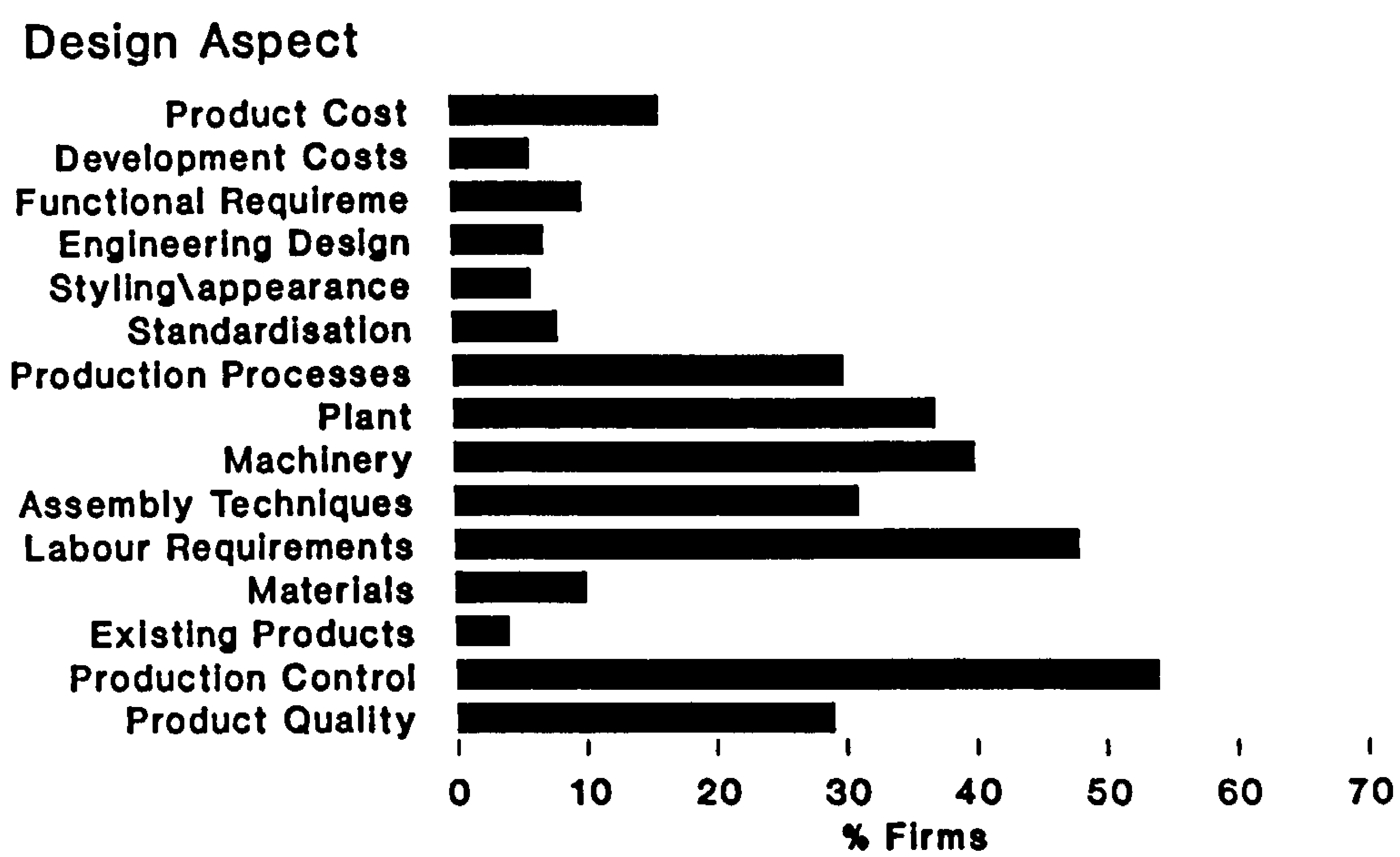


Fig 4-37 Production Stage & Des. Aspects

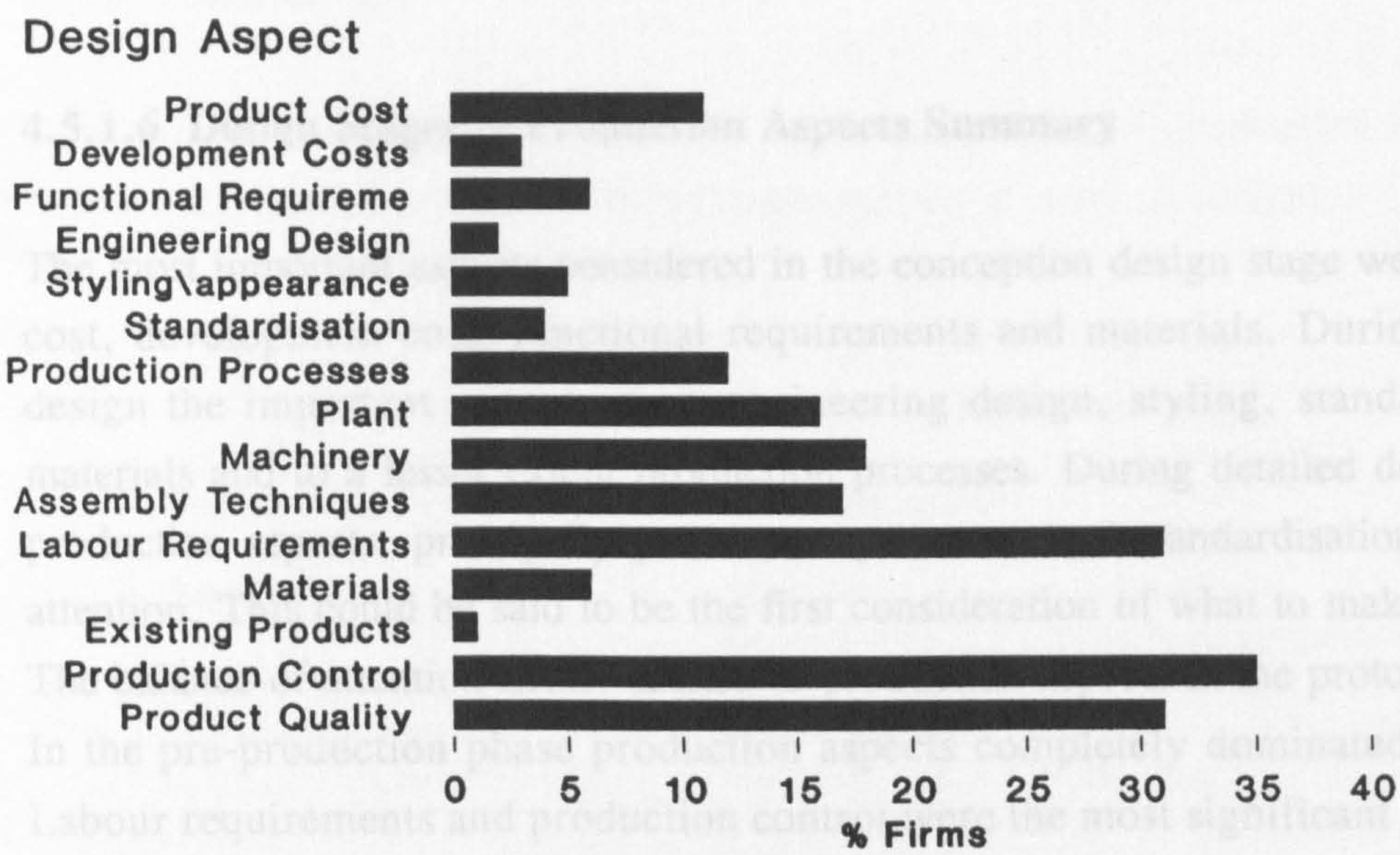
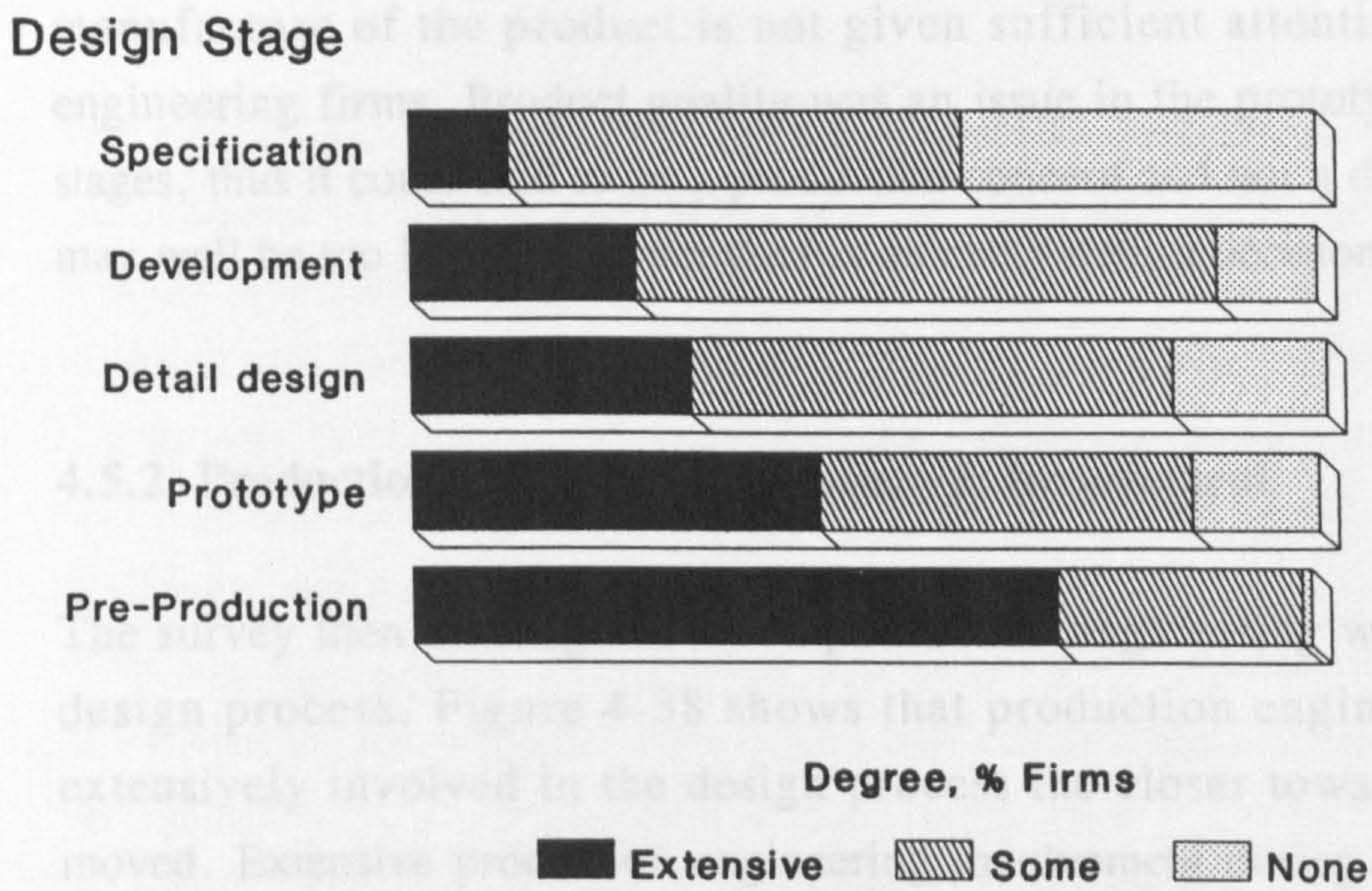


Fig 4-38 Production Engineering Involvem



4.5.1.5 Production Stage & Production Aspects

During the production design stage (Figure 4-37) production aspects were again most important, little attention being given to design aspects. The most important production aspects were production control, product quality and labour requirements. The attention paid to production processes, plant, machinery and assembly techniques had lessened compared to the pre-production stage.

4.5.1.6 Design Stages & Production Aspects Summary

The most important aspects considered in the conception design stage were product cost, development cost, functional requirements and materials. During detailed design the important aspects were engineering design, styling, standardisation, materials and to a lesser extent production processes. During detailed design some production aspects, principally production processes and standardisation, received attention. This could be said to be the first consideration of what to make and how. The balance of attention firmly shifted to production aspects in the prototype stage. In the pre-production phase production aspects completely dominated attention. Labour requirements and production control were the most significant production aspects considered. The prototype stage was the most important for the consideration of production aspects, considering all production aspects - how to make the product, by what means and by whom. Pre-production was devoted to refining how to make the product. This shows that the manufacturability of the product is not considered until after it is designed. Thus, the effective and efficient manufacture of the product is not given sufficient attention by mechanical engineering firms. Product quality was an issue in the prototype and production stages, thus it could said to be a production concern and not a design concern. This may well be too late to consider quality as many design decisions affect quality.

4.5.2 Production Engineering Influence & Involvement

The survey then investigated when production engineering were involved in the design process. Figure 4-38 shows that production engineering were more extensively involved in the design process the closer towards manufacture it moved. Extensive production engineering involvement during detailed design was confined to a third of companies, although 60%, or so, of companies had some involvement of production engineering during this stage. By the time the pre-production stage had been reached extensive production engineering increased to 60%. It can be concluded that production engineering were more extensively involved in the design process the closer it moved toward manufacture. Again this could well be too late to include production engineering knowledge into a product's design.

4.5.3 Conclusion

This section summaries the results of the consideration of production section and draws out the implications for firms' management of product design.

Table 4-1: Characterisation of Design Stages

Design Stage	*Characterisation*
Specification	Specification of the Product Fit with existing products & components
Detailed Design	Practicalities of Design Requirements of Production
Prototype	Practicalities of Production Honing costs within Spec
Pre-production	Make & Refine Manufacture of Product
Production	Produce "Quality" Products

The research found that the design phases can be characterised as follows (summarised in Table 4-1). The conception stage was when the specification of the product was considered, with some attention given to how it fitted in with existing products and components. The detailed design stage was when the practicalities of the design were worked out - ie. the "what to make" was designed. The requirements of production were also given some consideration - ie. production processes and assembly techniques. The prototype stage was where the costs of what was being made were honed, still keeping the product within specification. Now production aspects were given full consideration: the "practicalities of production" - how are we going to make them, how many on, which machines and by whom. The pre-production stage was for making the products and refining the process of making them. Production was focussed on making the products and their quality.

The research into the consideration of production aspects found that the prototype design stage was pivotal - where the balance shifted from design aspects to production aspects. Companies' current practice is thus to consider the manufacture of a product after it has been designed. This has ramifications for the efficiency and speed of manufacture of a product. Production engineering were involved the closer a product moved toward manufacture. Companies should endeavour to consider the production aspects of machinery, labour requirements and plant in the detailed design phase. There is also scope for production to be considered in the conceptual design stage, which at the moment concentrated on the specification of the product.

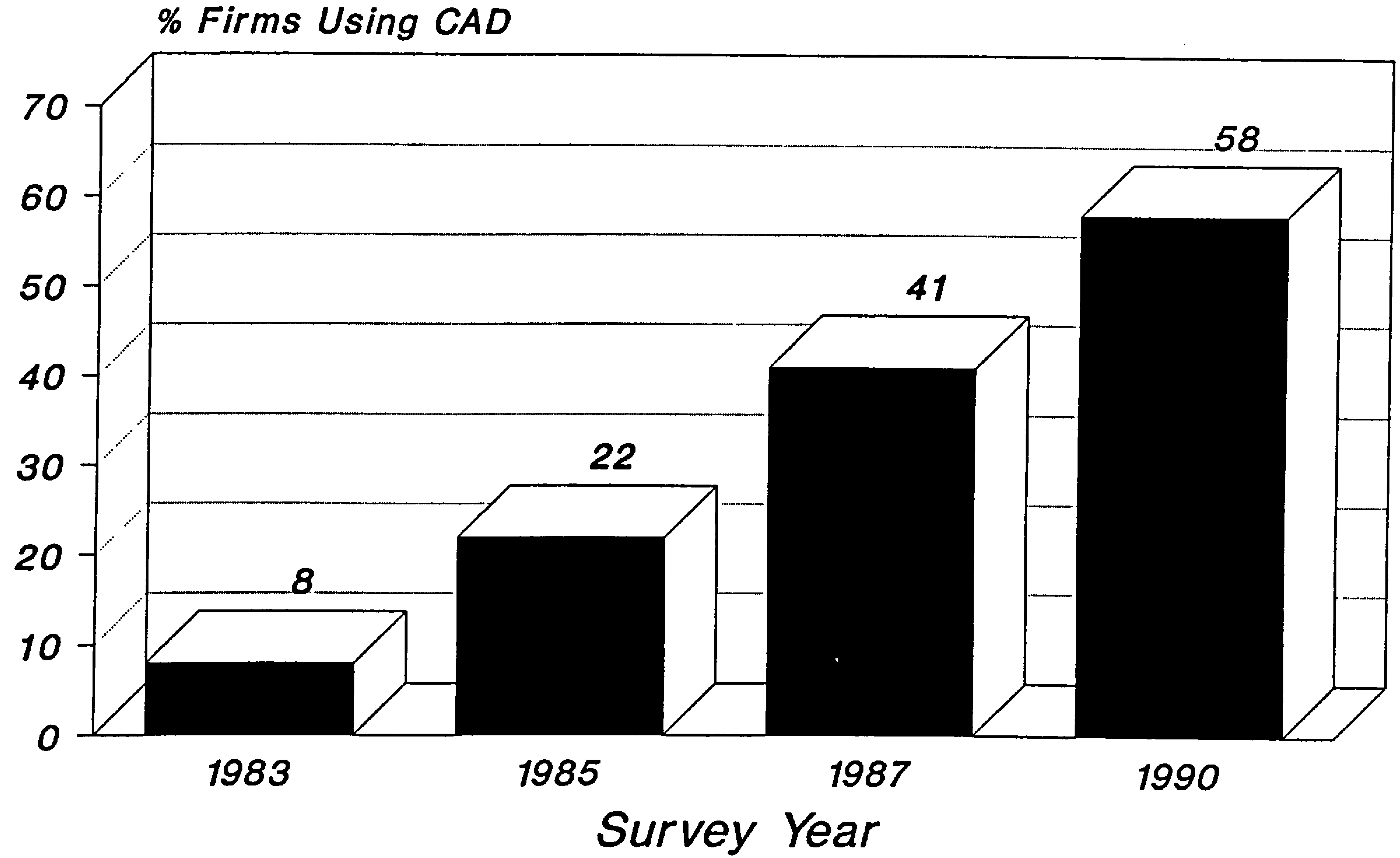
4.6 COMPUTER-AIDED DESIGN

This section of the thesis reports on the results of the survey of the use of computer-aided design. As discussed in the theory chapter, CAD has the potential to change the relationship between design and production functions radically. It can do this by first speeding up the design phase of product development and second by integrating the design and production functions. The questionnaire, as documented earlier, was constructed to test a number of hypotheses about CAD. The results are presented in the following order: the proportion and characteristics of firms using CAD; the uses firms made of CAD, including types of drawing, design analysis and its role in the design process; and finally the organisational effects of CAD upon firms. Specifically, the impact of CAD upon design modifications, standardisation, design - production co-ordination and integration, and achieved benefits were investigated. The section concludes with an analysis of the implications derived from the results of the survey and the issues to be investigated in the structured interviews. The first section analyses the characteristics of firms using CAD.

4.6.1 Characteristics of Firms Using CAD

This section analyses the characteristics of firms who have access to CAD. Firms can be characterised by their regional distribution, by establishment size, by sales turnover, by the age of production equipment, by type of process technology and finally by type of product manufactured. As a first step the survey identified the proportion of firms with access to CAD. The survey found that 63 firms (58%) had access to CAD equipment. This compared with the most recent Policy Studies Institute's (PSI) figure of 41% for mechanical engineering firms in 1987, the increase comparing with the PSI annual growth (see Figure 4-39, and Northcott & Walling, 1988). Hence, the majority of mechanical engineering firms had access to CAD.

Fig 4-39: CAD Users



Source: 1983-1987 PSI, 1990 This study.

Turning to the comparison of the regional distribution is more difficult. The PSI did not break down the regional use of CAD into industries. The regional distribution of all industries' use of CAD, therefore, will be compared against the survey's. The comparison is shown in Figure 4-40. It can be seen that for the key regions of the West Midlands and the South East (where the mechanical engineering industry is concentrated) there is agreement between the two sets of figures. The higher figures of the PSI result from the inclusion of intense users of CAD, that is, motor vehicles and electrical engineering. Similarly, the PSI's high figure for the East Midlands is explained by the concentration of the clothing industry in that region (Bosworth et.al, 1990).

Figure 4-41 presents the results of the analysis of firms with access to CAD classified by establishment size, as measured by the number of employees. Firms using CAD are concentrated in the large and medium sized range, 50 to 1000+ employees. In fact, as can be seen from the last two points on the upper line all large firms (those in the two top size bands, although the latter band represented one firm) use CAD. This result is in agreement with the trend of the PSI's figures for these two size bands. Further, more than two thirds of medium sized firms (200 - 500) used CAD. Also two thirds of the larger small firms (50 - 200) used CAD. Thus, establishment size affected the use of CAD by firms, showing a definite trend for CAD use to increase with size. The PSI did not produce an analysis of CAD use by sales turnover, hence, it is not possible to make a comparison. Figure 4-42 presents the tabulation of turnover. This shows that below a cut-off point of two million pounds firms were less likely to use CAD. Above this point the majority of firms used CAD. The survey then attempted to investigate the influence of production and product characteristics upon CAD use. The two characteristics of production examined were age of production equipment and process technology. The first of these is depicted in Figure 4-43 below.

Fig 4-40 CAD & Regional Distribution

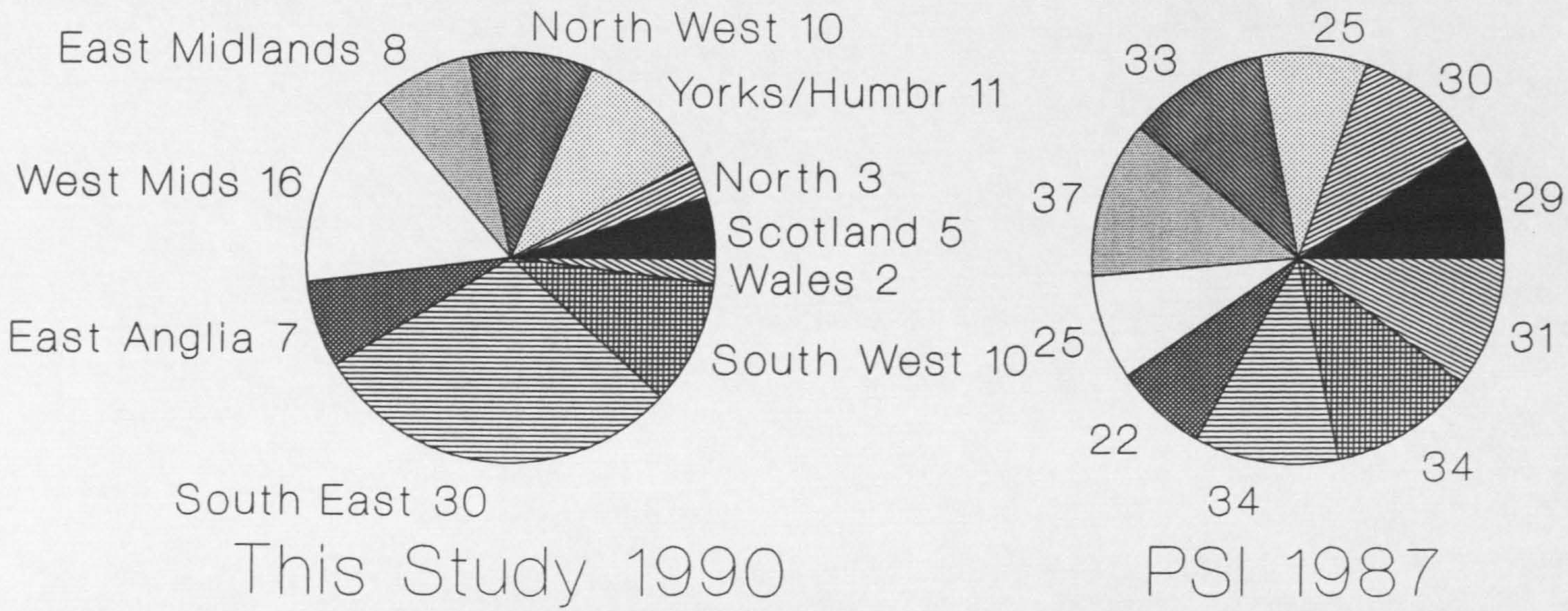


Fig 4-41: CAD and Establishment Size

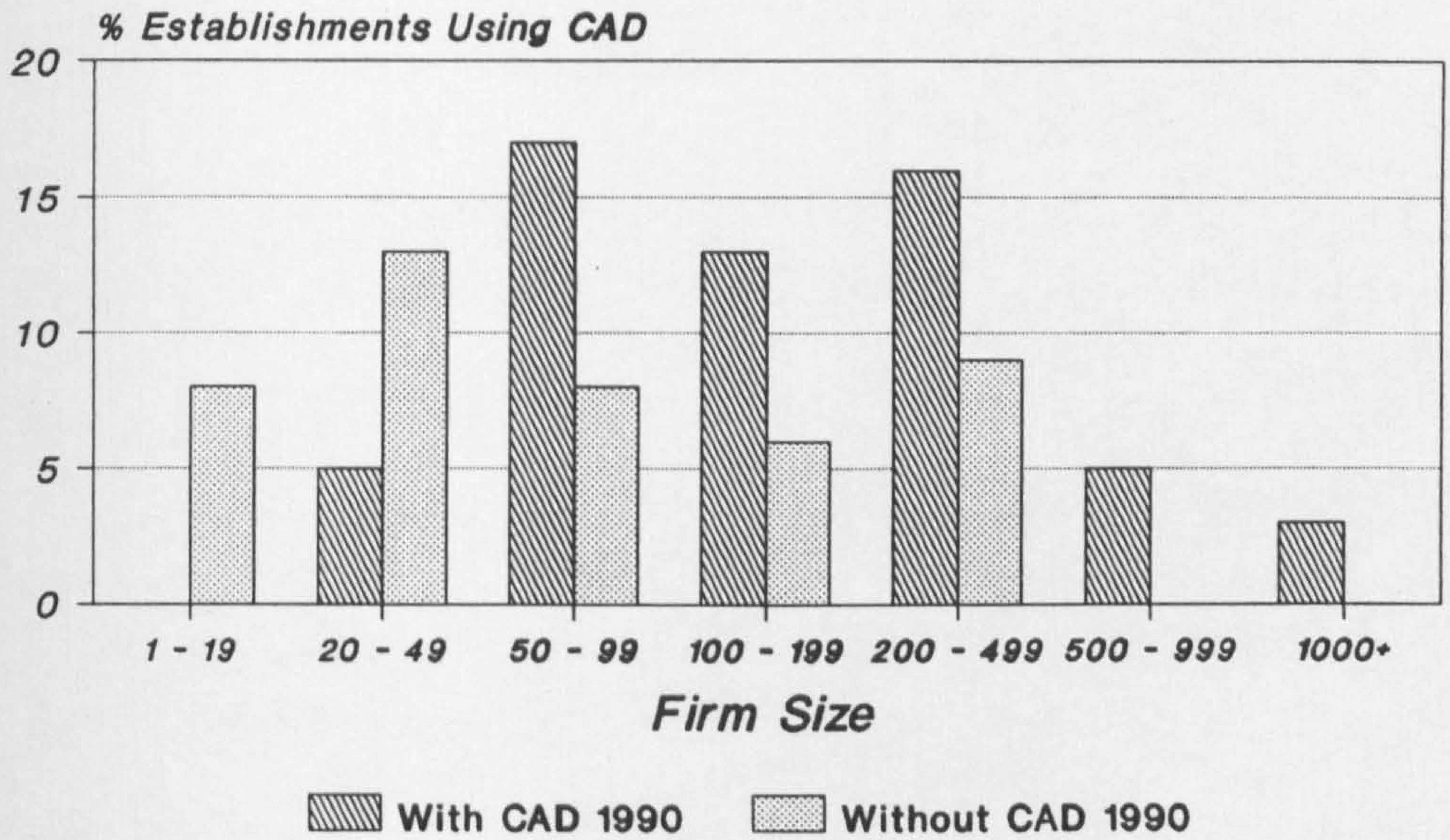
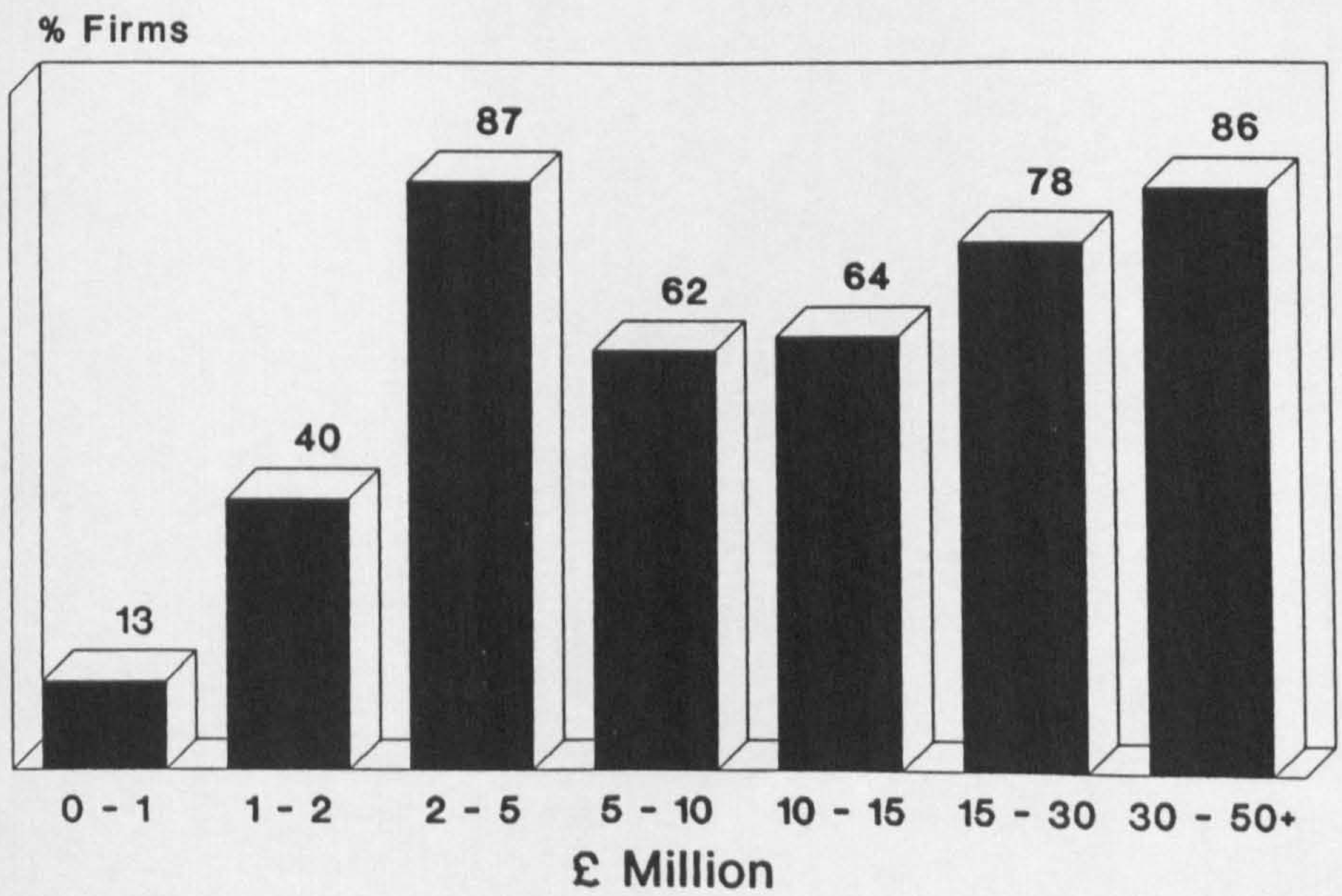


Fig 4-42 CAD & Sales Turnover

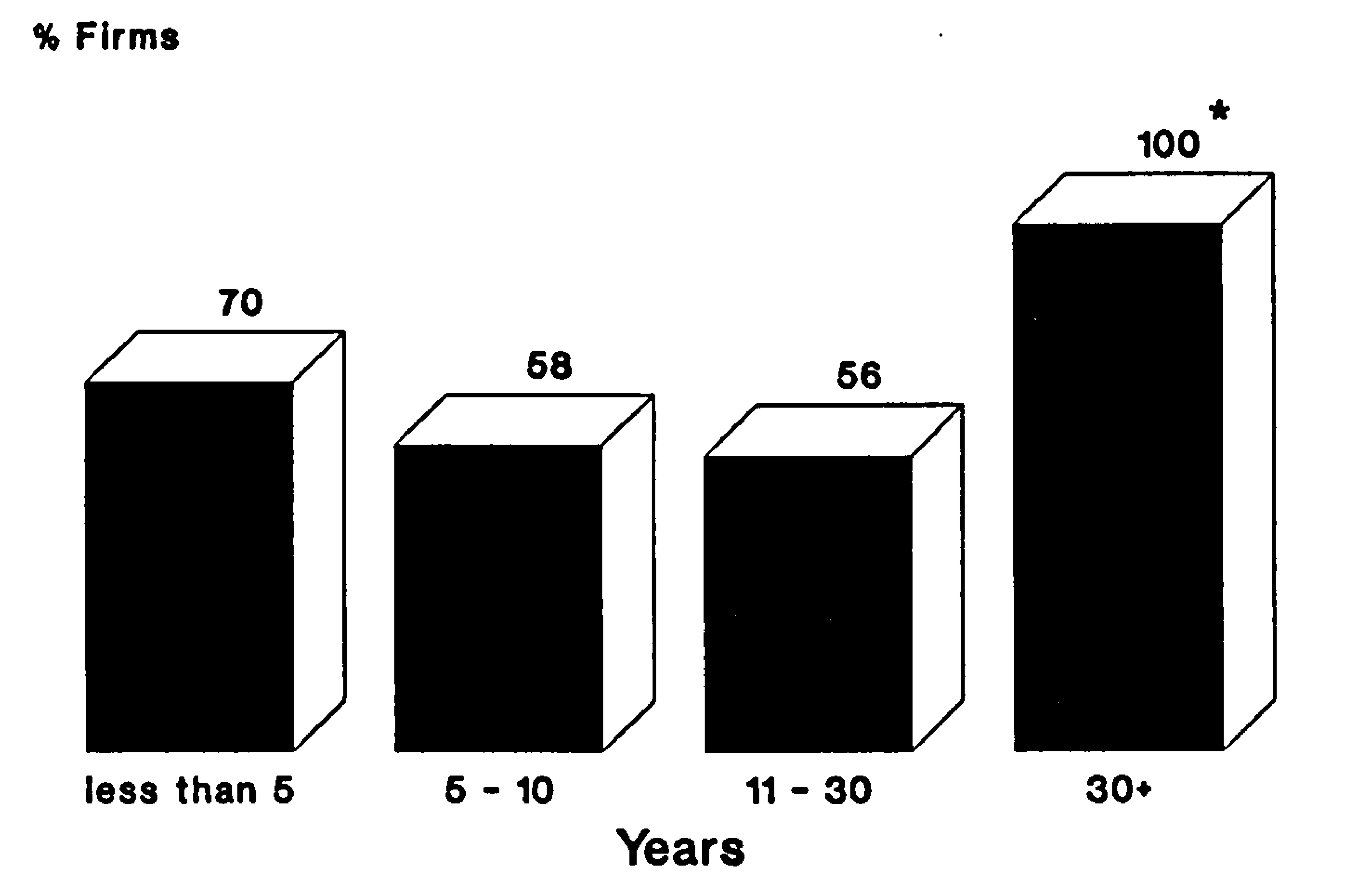


The results of production equipment age showed that across all ages of production equipment there were more CAD users than non-users. Even firms with production equipment up to 30 years old used CAD. However, the hypothesis that only firms with new production equipment (less than five years old) would use CAD was confirmed. The second influence of production upon CAD use is that of the type of dominant process technology used by the firm (Figure 4-44). Here it can be seen that CAD users are concentrated in the batch and one-off process technology categories. Mass/ flow line process technology firms were unlikely to possess CAD.

Finally, an analysis of the influence of product characteristics upon CAD use was conducted. Products were classified into three types depending upon their destination after leaving the firm: final products (eg. capital goods), intermediate (components) and consumer. The analysis showed that producers of final products were the largest users of CAD. Intermediate product makers came second with firms producing both intermediate and final products third. Lastly, only a few consumer product firms used CAD, although their under-representation in the survey may be a contributing factor to this result.

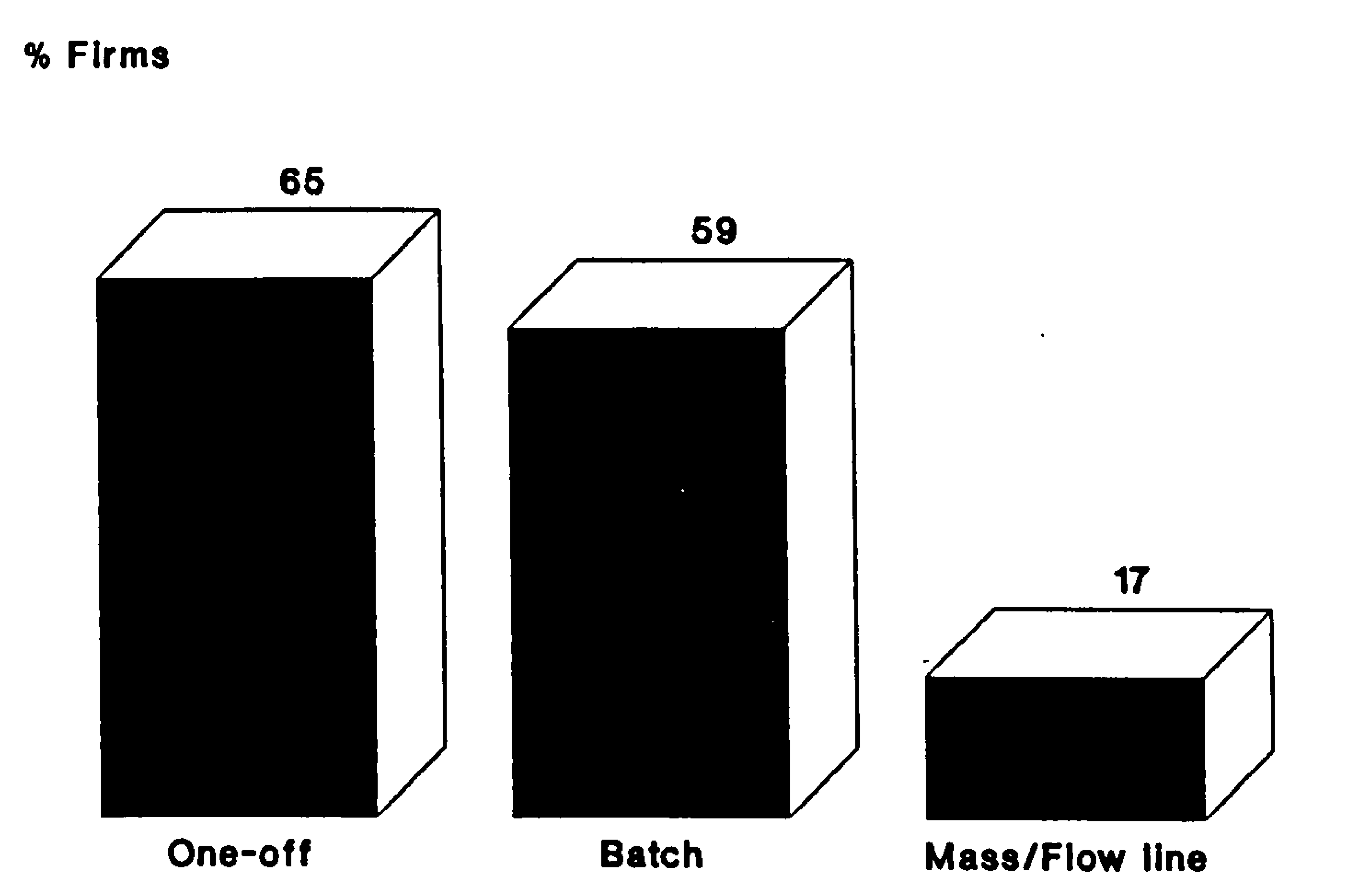
In conclusion the characteristics which determined CAD use were found to be regional location (South East and West Midlands), establishment size (medium and, particularly, large establishments), turnover (above two million pounds), production equipment age (less than five years old), process technology (one-off and batch had CAD but not mass/ flow line) and product type (final and intermediate). The survey then went on to investigate the types of use that firms made of CAD.

Fig 4-43 CAD, Production Equipment Age



• Only one firm.

Fig 4-44 CAD & Process Technology



4.6.2 Analysis of Firms' Use of CAD

The survey, in contrast to previous studies, also examined the industry's use of CAD equipment. This considered the types of design put on the CAD system, the types of drawing performed on the system, the use of design analysis, the use of CAD for conceptual design, the use of CNC machine tools and the stage during the design process when CAD was used.

The survey considered whether new designs, old designs or both types were put on the CAD system when first purchased. After purchasing a system half the firms put only new designs onto it and the other half put a proportion of old and new designs on. Only one firm transferred all design work onto the system. Half the firms entered a database of existing parts. Sixty two per cent of firms used a database of standard components (with standard dimensions). This finding was confirmed by Simmonds & Senker (1989). They reported that all 14 of their user firms had created parts libraries. Thus, CAD was used equally for old and new designs with the majority of firms possessing databases of components.

The survey also investigated the use that firms made of the CAD system. Simmonds & Senker (1989) in their longitudinal case studies of firms reported that CAD use was mainly restricted to drawing only and that the more advanced features and possibilities of CAD were not used. The research was designed to test this hypothesis for the mechanical engineering industry. The survey showed that 83% of CAD user firms used it for 2D drawing, 37% for 3D wire frame drawing and 19% for solid modelling (see Figure 4-45). Firms which exclusively used CAD for 2D and 3D drawing comprised 14% of users. Ten per cent of users used CAD for all three types of drawing. Hence, the overwhelming majority of firms (83%) used CAD for 2D drawing, 56% exclusively so. This confirms the hypothesis that CAD is used principally for drawing and primarily 2D drawing. This hypothesis holds for the mechanical engineering industry in general (in 1990). This, is the case in spite the intervening eight year time span since Arnold & Senker's first study (1982-1990).

Fig 4-45 CAD and Drawing Type

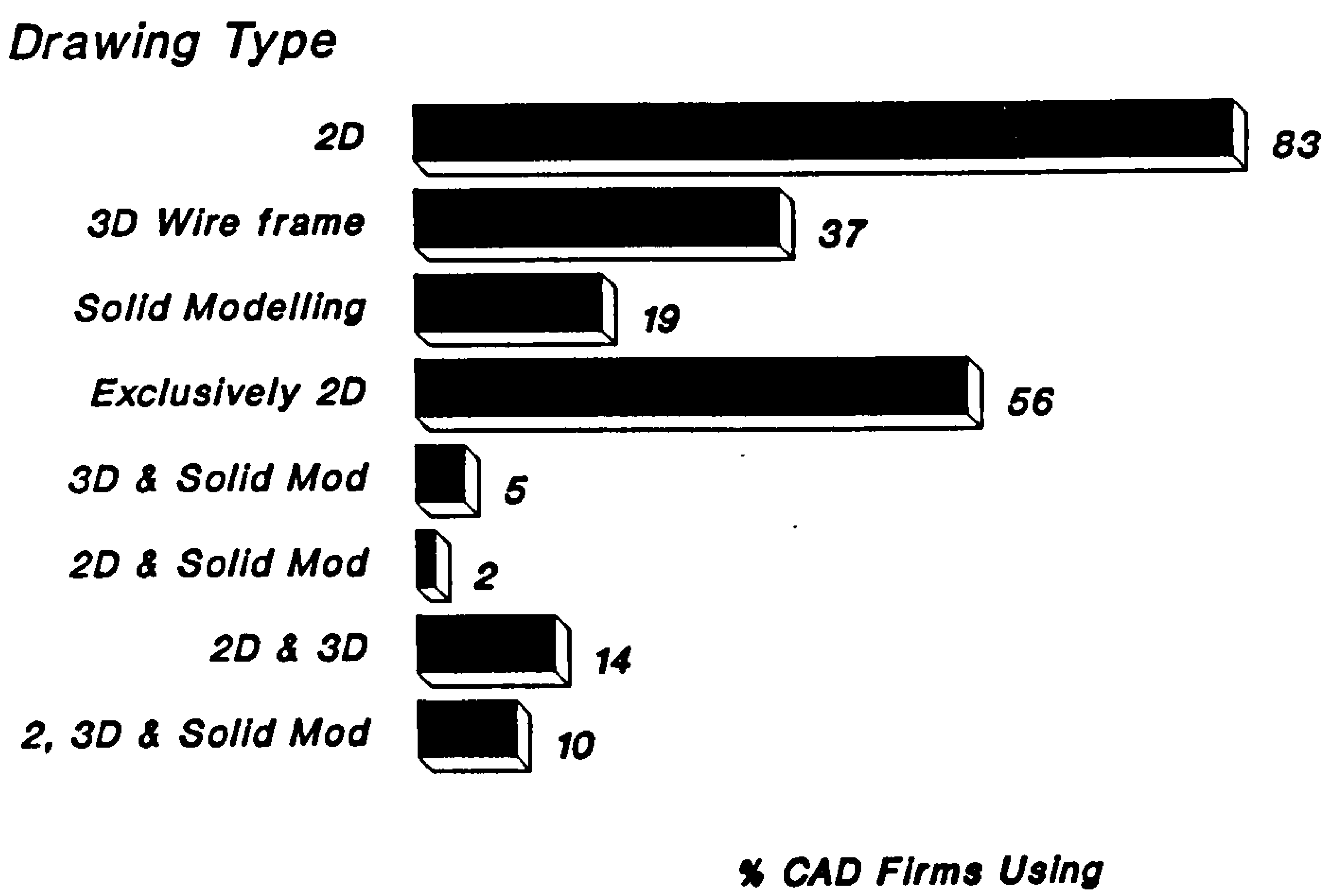
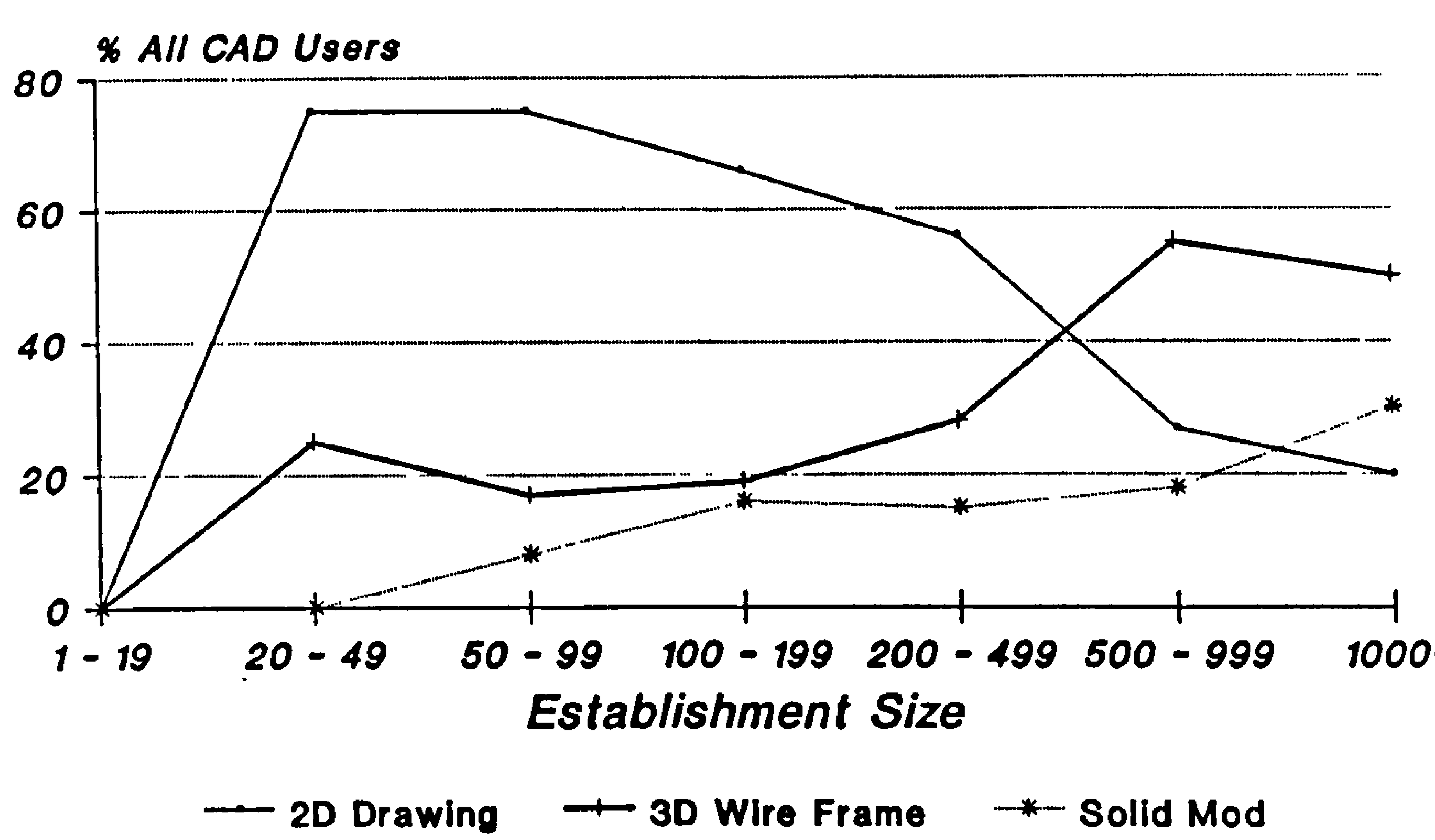


Fig 4-46 Drawing Type Establishment Size



Encouragingly, nearly 40% of firms used CAD for 3D drawing and 20% for solid modelling. Simmonds & Senker point out, however, that firms who possess 3D ability have not used it to the full. Only three of their 14 companies were using 3D design regularly (1989). The high percentage figures of the survey for 3D design augur well for realising the potential benefits of CAD in the future.

The survey also investigated the effect of establishment size upon the type of drawing in use. The results are shown in Figure 4-46. Here it can be seen that 2D drawing is concentrated in the smaller establishments (less than 500 employees). The "medium" (200+) sized and large firms mainly account for the use of 3D wire frame and solid modelling. These two types of drawing tended to follow the industry establishment size distribution of CAD use, that is increasing with size. The other aspects of CAD use examined by the survey were its use for compiling bills of material, die and tool design, design analysis, and conceptual design. Fifty six per cent of firms used CAD for compiling bills of material/ parts lists. Only 8% of firms used CAD for die and tool design.

The next sophisticated use of CAD is its use for design analysis. The results from the survey (shown in Figure 4-47) were: finite element analysis (13%), component interference checking (32%). Forty per cent of firms used CAD for design for assembly, although care must be taken in interpreting this result as this was what firms understood as "design for assembly". Only one firm reported it used CAD for design for automatic assembly. Two firms reported they used expert systems on their CAD system.

As regards the most advanced form of CAD use for conceptual design 35% of firms reported they used CAD for "mechanical/ kinematic design". Once again care must be taken interpreting this finding, relying as it does upon firms' understanding of that phrase; at worst it could mean that they simply use CAD for 2D mechanical drawing, at best that they genuinely use CAD for conceptual design. The survey does not allow this result to be clarified. Other uses of CAD reported by users were: customer presentations, performance data, and weight and centre of gravity calculations. It can be concluded that only a small minority of firms (at most the 30% using component interference checking) used CAD for more sophisticated applications. The most sophisticated use made by firms of CAD is for compiling bills of material (56% of users).

Fig 4-47 Sophisticated Use of CAD

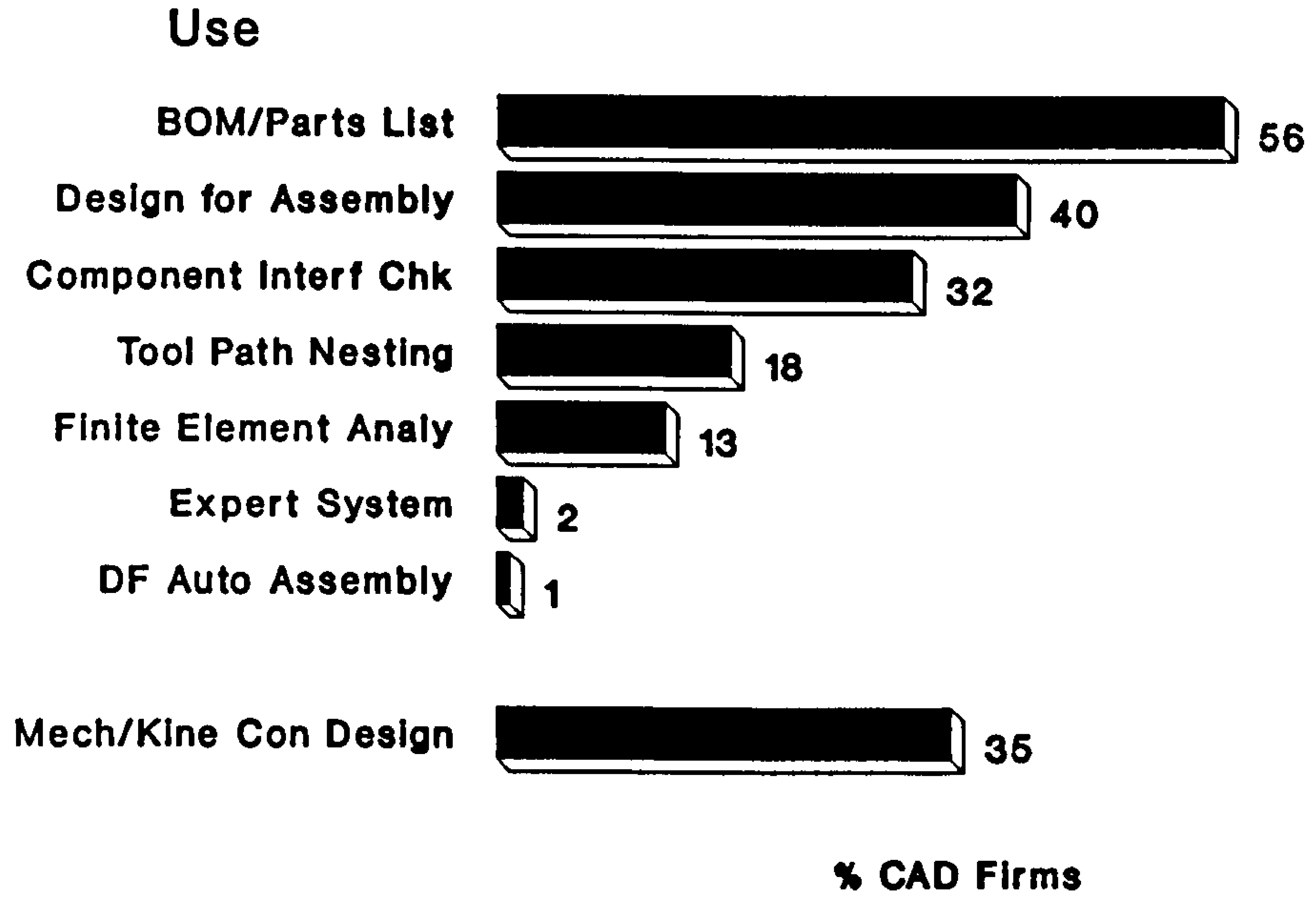
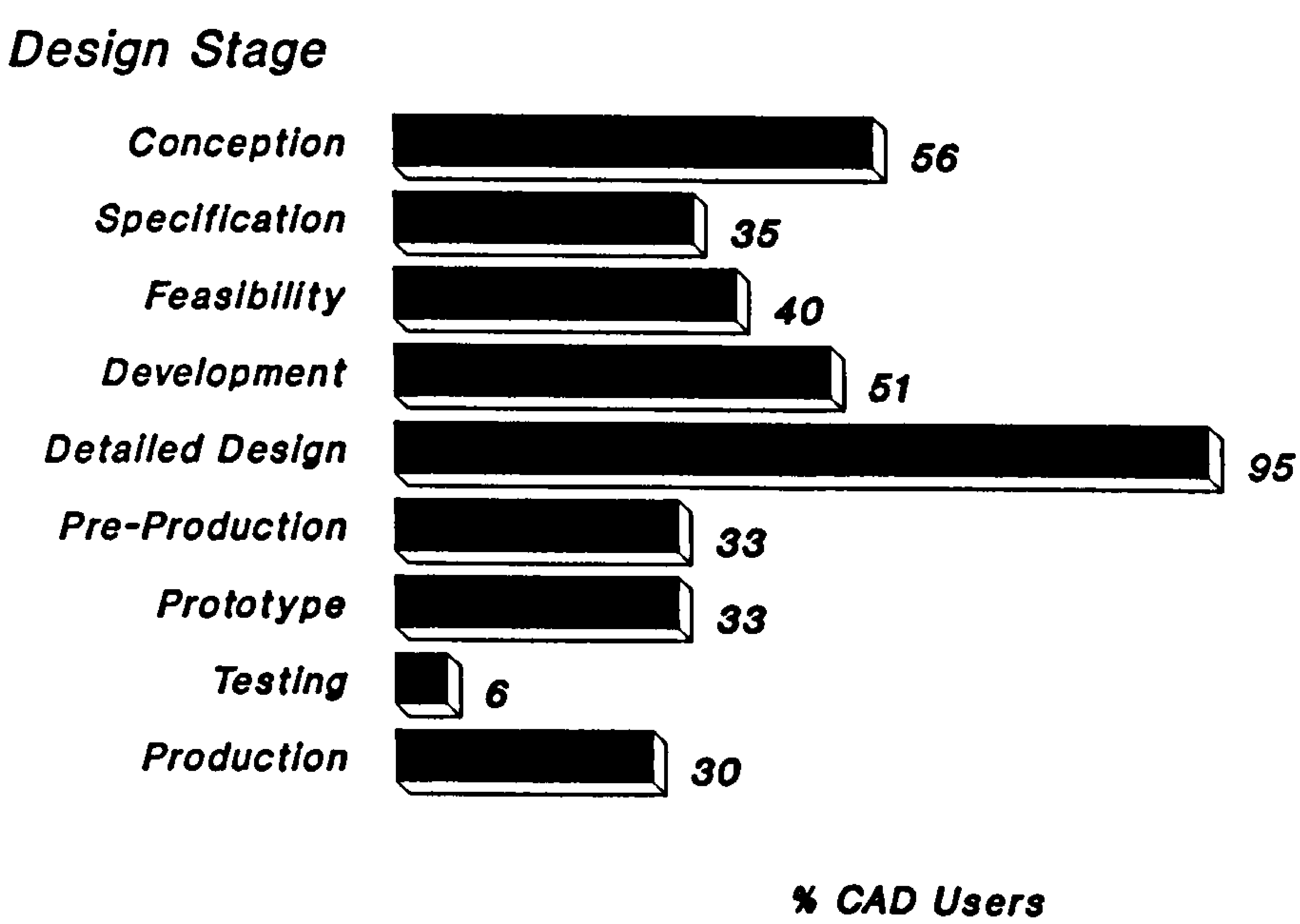


Fig 4-48: CAD & Design Stage



The survey then examined the use of CNC machine tools by CAD user firms. A quarter of CAD user firms reported using three axis numerical or computer numerical controlled (N/CNC) machine tools. Only three firms used five axis N/CNC machine tools, one each in the two upper establishment size bands. Of these three, one was able to simulate machining on its CAD system. Nearly all three axis users reported being able to simulate machining. Eighteen per cent of firms used CAD for tool path nesting. Simmonds & Senker reported that the interchange of CNC data took place by tape rather than electronically (1989). They also reported that although firms possess CAM it is not linked to the CAD system. This is somewhat contradicted by the survey which showed that nearly all three axis CNC users could simulate machining and thus were linked to CAD. The analysis of establishment size showed that all large users had three axis CNC, with the majority of firms with more than 50 employees also possessing it. The possession of CNC and simulation of machining represent technology bridging the gap between design and production. In order to determine the extent of this bridging provided by CAD its use during the various stages of design was investigated.

Figure 4-48 shows the results of asking firms during which design stage they used CAD. This shows that, as anticipated, CAD is overwhelmingly used in the detailed design phase of design, that is, for actually producing drawings of the product. Also a half of users used CAD in the development stage. Again, as expected, very few firms used CAD during testing of the product. Surprisingly, however, just over half of users used CAD during the conception stage of design. Also somewhat unexpected was the finding that around a third of users use CAD in the specification, feasibility, pre-production, prototype and production stages. The latter use, during production, indicates expensive design modifications are being carried out during manufacture of the product. CAD use during the specification stage indicates that companies are using CAD to aid in the drawing up of the design specification - an encouraging sign indicating that firms are making use of the abilities of CAD. Simmonds & Senker (1989) sound a note of caution here, stating that some of their respondents (asked in 1988) said that most of the current CAD software was unsuitable for conceptual design work. However, the consistent use (30% of users) of CAD in the specification and feasibility stages of design indicates that firms are beginning to exploit the full potential of CAD. The next section presents the analysis of the organisational effects of CAD upon firms.

4.6.3 Organisational Effect of CAD on User Firms

Many studies report the gains of CAD as arising from: improved quality, rapidity of design (lead times), ease of modification, shortening of development cycles, customisation and sophistication of products (meeting customer needs), repeat designs, better presentation of tenders, need for increasingly complex products and increased quality and clarity of drawings (Arnold & Senker (1982), Blackburn et.al (1985), Campbell & Warner (1988), Ingham (1989)).

This section attempts to measure some of these organisational impacts of CAD. The problem of measuring these effects is a difficult one. It was decided to adopt two measures of the impact of CAD. These were intended to measure the improvement to product design due to the use of CAD. First, the amount of modification to a product's design after drawings had been handed over to production personnel. Second, the number of standard components used in the design. These two measures can easily be determined, and verified if necessary. Other measures, however, such as the effect on quality, which are subjective are hard to quantify. The other impacts of CAD measured were intended to determine if CAD had bridged the gap between design and production. These measures were production engineering access to the CAD system, and the effect of CAD upon co-ordination and integration between design and production departments. If CAD could bridge the gap between design and production the potential competitive benefits of this are great.

The survey first investigated the benefits that CAD users had been able to achieve (see Figure 4-49). The analysis of benefits shows that the overwhelming advantages of CAD were achieved in two areas, namely, ease of modification and rapidity of design. This could explain the achievement of shorter lead times from initial stage to commercialisation. Other more manufacturing oriented benefits (which would reduce costs): simplify/ ease manufacture, simplify assembly and increase consideration given to manufacture were only achieved by around a fifth of users. The customer oriented benefits of increased customisation and sophistication of the product were also only achieved by a fifth of users. Finally, the time saving benefit of CAD was not seen to feed into allowing shorter production runs of products. Other benefits cited by single users included: CAD/CAM link for prototype manufacture, improvement of sales presentation drawings, fewer drawing errors, improved accuracy, increased standardisation, better quality output/designs, and shortened lead time for some items (eg. Bills of Material).

Fig 4-50 CAD & D-P Coordination

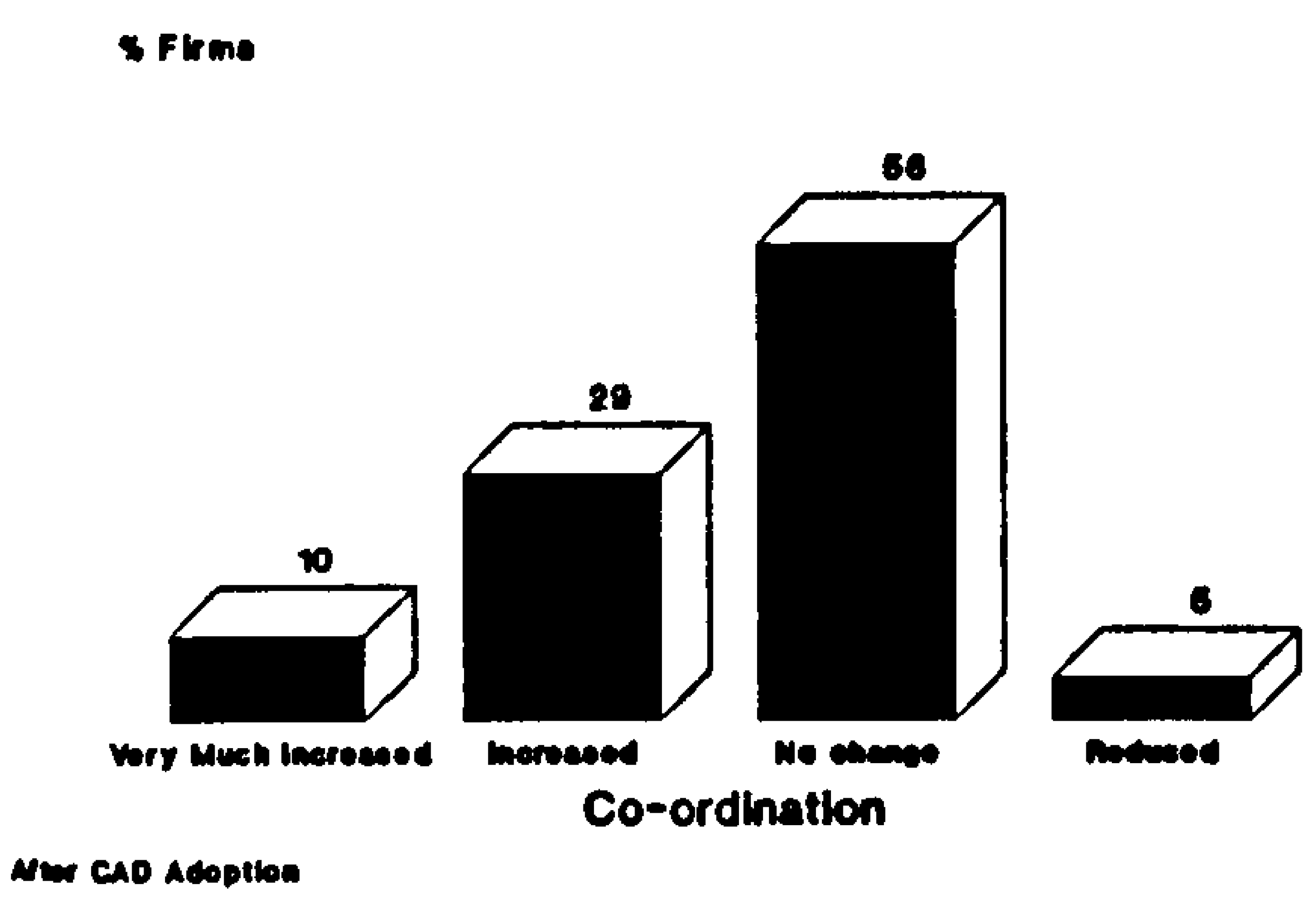


Fig 4-51 CAD & D-P Integration

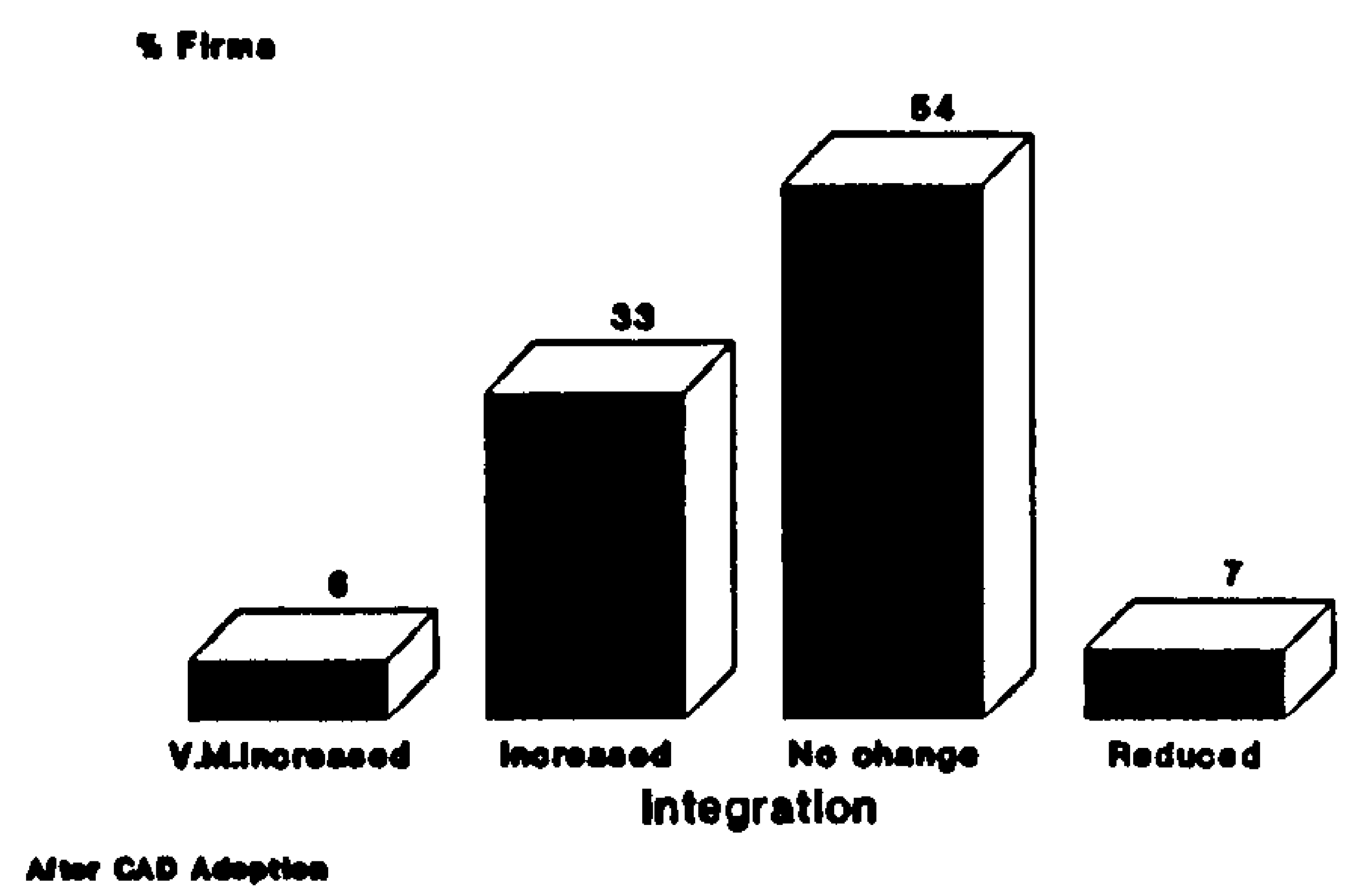
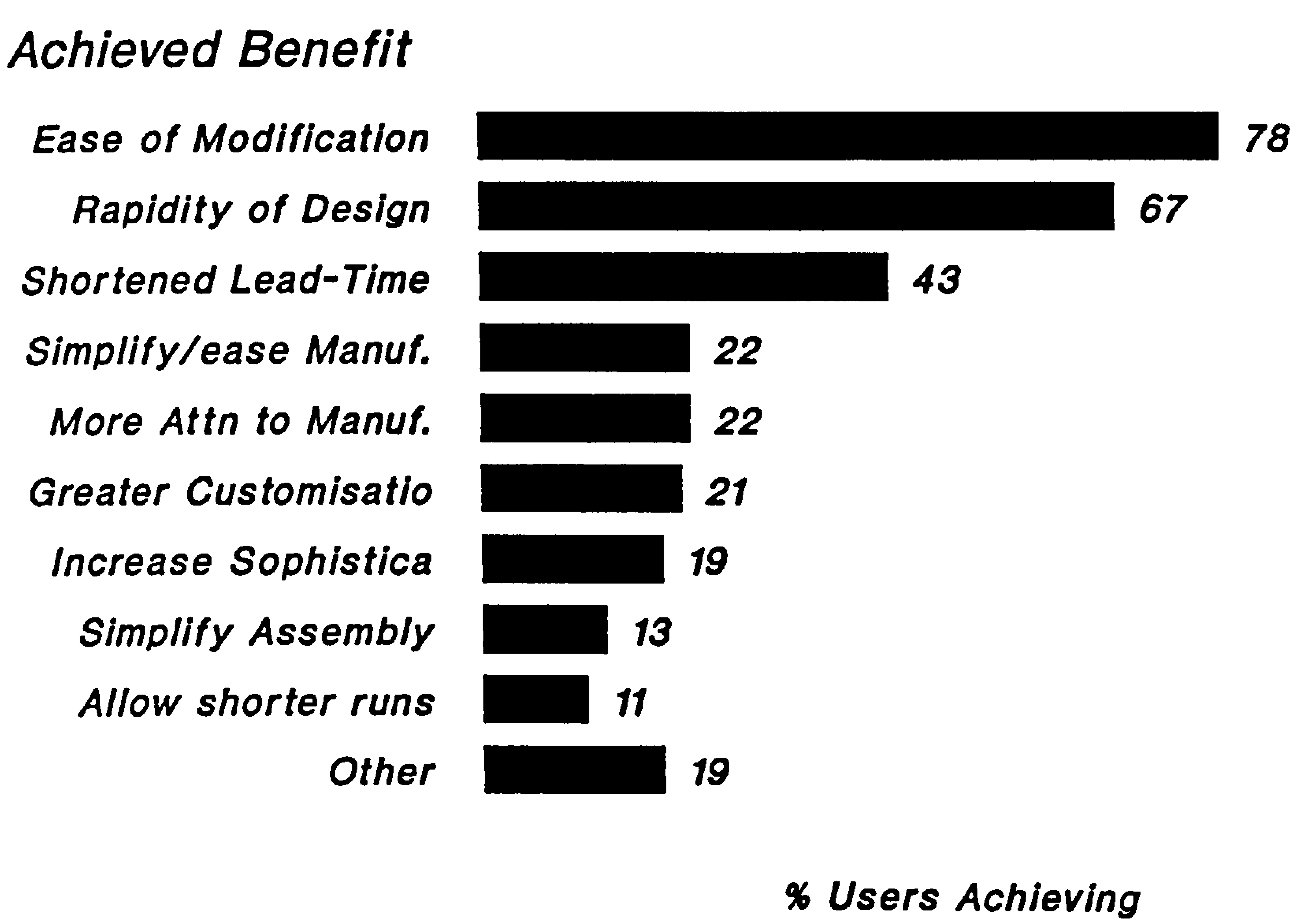


Fig 4-49: Achieved Benefits of CAD



This ranking of benefits was reproduced when users were asked which benefit was the most important. Thus, rapidity of design and ease of modification were each thought most important by 20% of users. Shortened lead time was most important for 8% of users and simplification/ ease of manufacture of the product by 3%. Only single users thought the benefits of increased customisation and sophistication were the most important. From these two analyses of benefits and their importance two conclusions can be drawn. First, that the more sophisticated benefits of CAD remain unrealised for the majority of CAD users. Second, that the ability of CAD to integrate production considerations into the design process has not been developed.

This was further investigated by the survey in considering the impact of CAD upon the relationship between the design and production departments. In order to test this, respondents were asked if production engineering had access to the CAD system. The results showed that in the majority of firms (73%) they had no access, in 17% they were able to change designs and in 8% production engineering were only able to view designs on the CAD system. Thus, almost a fifth of user firms allow their production engineering staff to change designs on the CAD system. This is either to preempt changes during manufacture or reflects changes made during manufacture. Most firms, however, did not allow production engineering to influence designs held on the CAD system. This means production knowledge cannot be incorporated into the product design in order to ease its manufacture.

The survey also considered whether CAD had affected the degree of co-ordination and integration between design and production in the design process. The majority of users (56%) reported co-ordination between design and production did not change after the introduction of CAD, 29% reported co-ordination had increased and 10% reported it had very much increased (Figure 4-50). Only two users claimed it had decreased. A similar picture emerged for design - production integration (Figure 4-51). Most users reported no change (54%), increased integration (33%) and very much increased (6%). Thus, around 40% of users reported CAD had increased integration between design and production after its adoption. Hence, for both co-ordination and integration just over a half of users reported no change and 40% reported an improvement after CAD adoption. In conclusion, these analyses mean that firms' competitive position has not improved through CAD use.

The results of the first measure of improvement to product design, component modification, are shown in Figure 4-52. It shows the modifications carried out after drawings have been transferred from design to production for CAD user and non-CAD user firms. It would be expected that modifications would be reduced for CAD user firms, as the design could be perfected on the CAD system before being produced. Contrary to expectation CAD use increased the amount of modification after drawing transfer. Only a small number of firms made more than 30% of modifications, those that did are exclusively CAD users. From this it can be concluded that CAD has either increased the ability of firms to make design changes after the handover of drawings to production, or has had a detrimental effect upon the number of such changes made (ie. increased them unnecessarily). The survey does not indicate which of these two explanations is true. Thus, follow up structured interviews were undertaken. Before discussing these the impact of CAD upon standardisation will be considered. The analysis of the effect of CAD on standard components can be drawn into the picture to clarify this (see Figure 4-53). This shows that CAD users have achieved higher percentages of standard components in their designs. There are two possible explanations for this. First, it can be hypothesised that CAD would increase the number of standard components in a product's design, due to its ability to store them. This would be of great benefit in lowering manufacturing costs and reducing lead times. The alternative hypothesis is that firms with more standard components are more likely to benefit from CAD and, therefore, adopt CAD. The survey could not distinguish between these two alternative explanations. Further research on this, before and after CAD adoption, is required. The research did attempt to resolve this through structured interviews of firms who used CAD. The results of these structured interviews are presented, below, in Chapter five.

Fig 4-52 CAD & Modification

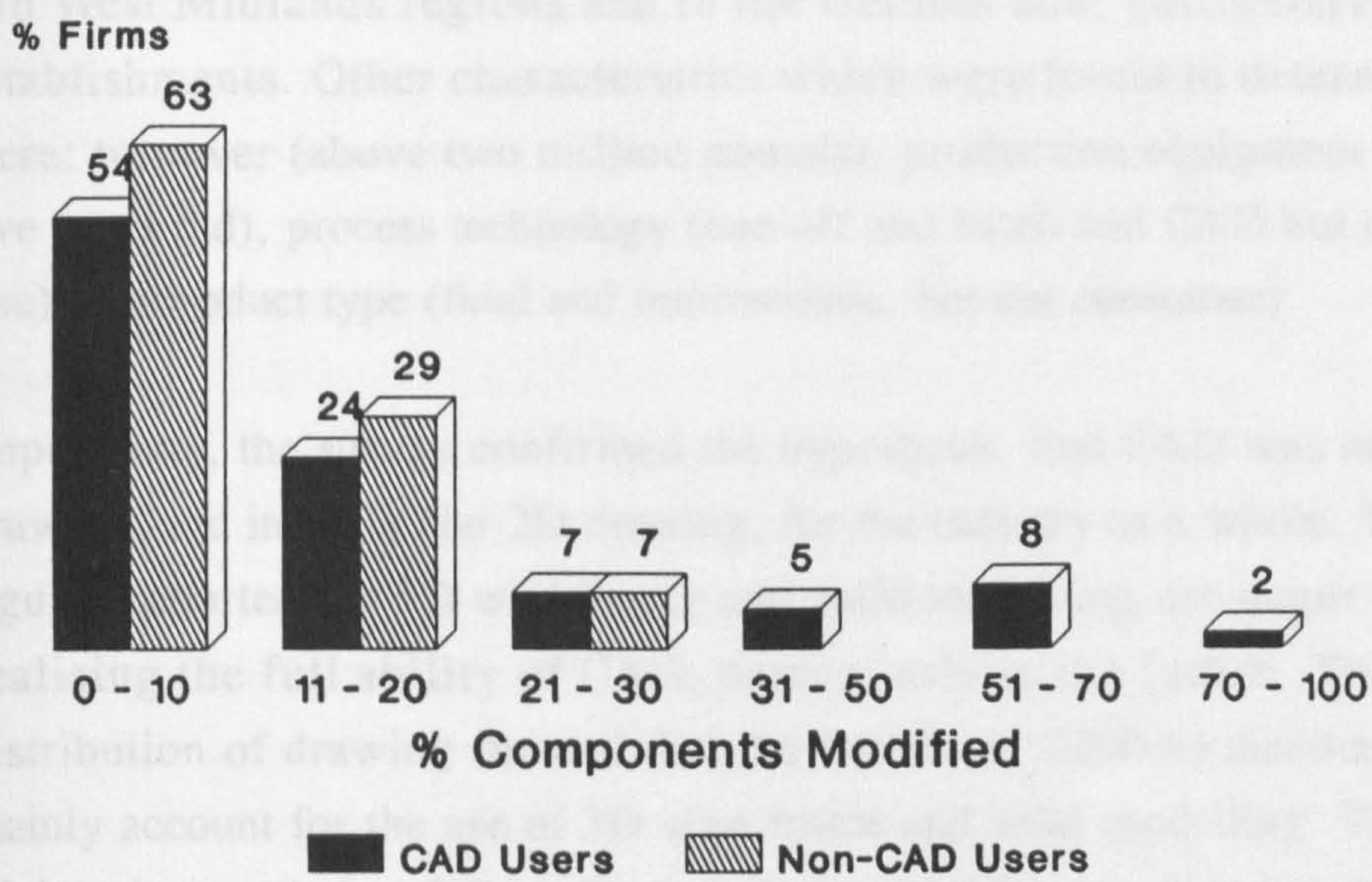
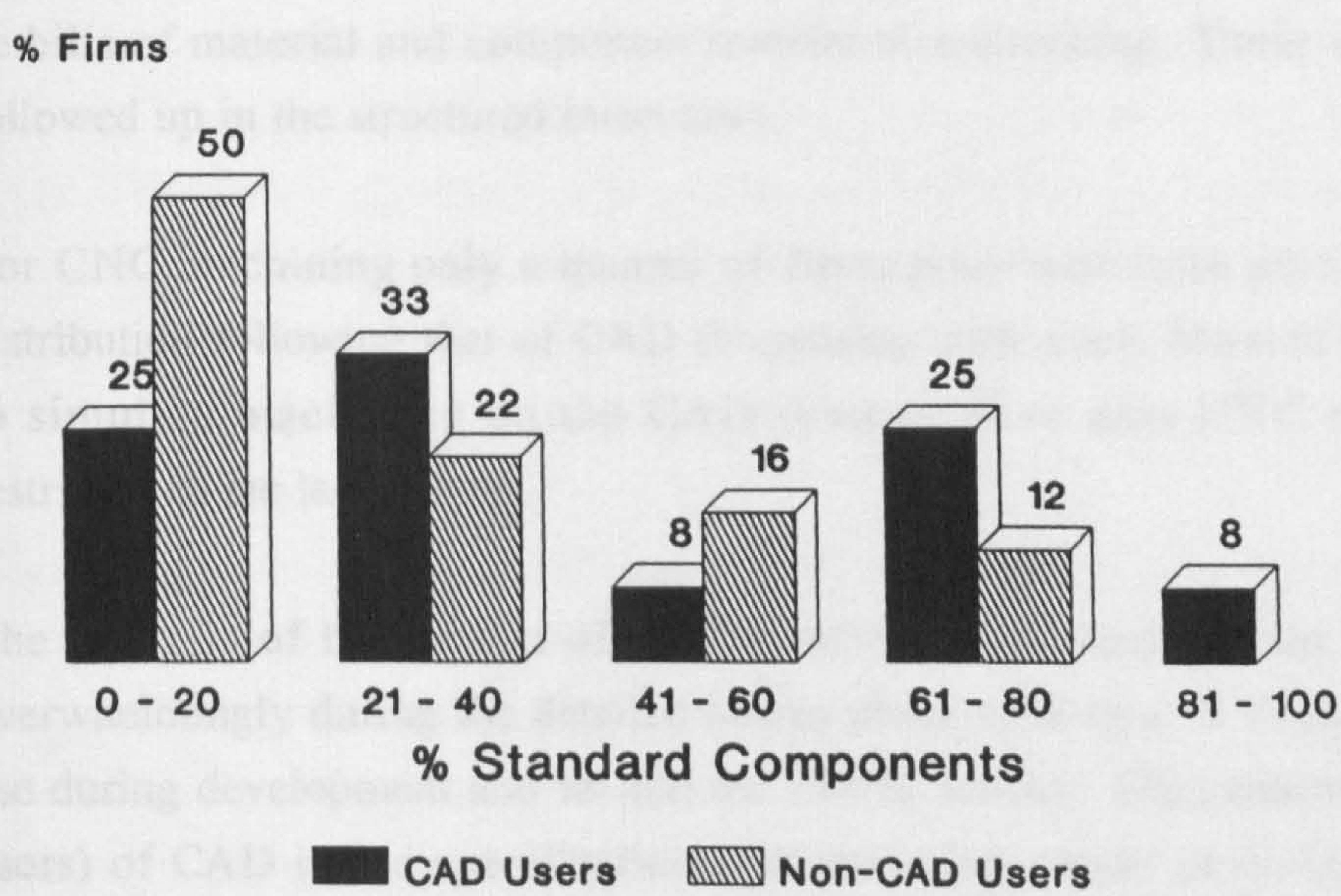


Fig 4-53 CAD & Standardisation



4.6.4 Conclusion

The results for CAD of the survey of the UK mechanical engineering industry, were found to be consistent with previous research. It was found that 58% of surveyed companies, and thus the UK mechanical engineering industry, used CAD. This, and the regional and establishment size distribution of users were in agreement with previous studies. User firms were concentrated in the South East and West Midlands regions and in the medium and, particularly, large sized establishments. Other characteristics which were found to determine CAD use were: turnover (above two million pounds), production equipment age (less than five years old), process technology (one-off and batch had CAD but not mass/ flow line) and product type (final and intermediate, but not consumer).

Importantly, the survey confirmed the hypothesis that CAD was mainly used for drawing, and in particular 2D drawing, for the industry as a whole. The percentage figures reported for 3D wire frame and solid modelling use augur well for firms realising the full ability of CAD, particularly in the future. The size of firm distribution of drawing showed that the "medium" (200+) sized and large firms mainly account for the use of 3D wire frame and solid modelling. These two types of drawing tended to follow the industry establishment size distribution of CAD use, that is increasing with size. Contrarily, 2D drawing is concentrated in the smaller establishments (less 500 employees). The results of the survey for more sophisticated uses of CAD for design analysis and conceptual design were difficult to interpret. They did show that only a minority of firms claimed to use some form of design analysis. The most significant sophisticated uses of CAD were found to be bills of material and component interference checking. These issues would be followed up in the structured interviews.

For CNC machining only a quarter of firms possessed three axis CNC, with the distribution following that of CAD (increasing with size). Most of them were able to simulate machining on the CAD system. Five axis CNC machines were restricted to the large firms.

The analysis of the impact of CAD confirmed the expectation that it is used overwhelmingly during the detailed design phase of design. It also confirmed CAD use during development and its non-use during testing. The consistent use (30% of users) of CAD in the specification and feasibility stages of design indicates that firms are beginning to exploit the full potential of CAD. Also, the achieved benefits of CAD were mostly the straight forward ones of ease of modification and rapidity of design. Secondly, there was only a marginal improvement in the amount of co-ordination and integration between design and production functions as a result of CAD use. This was underlined by the lack of access to the CAD system by production engineering. Hence, CAD was used by the majority of firms in simple applications of drawing, and the benefits that resulted were ease of modification and rapidity of design. If CAD had been applied to more sophisticated applications there may have been greater gains. The gains from the involvement of production engineering in design and using CAD to improve the manufacture of products would produce significant competitive advantages in terms of quality, cost and time. These, however, remain to be realised by firms.

An important outcome of the survey was the finding that CAD had increased the amount of modification carried out to designs after they had been transferred to production. This, when taken together with 30% of firms using CAD in the production stage of product design and the ease of modification benefit demonstrates that firms are changing designs while they are in production. Two propositions follow from this. First, that these modifications during production have a detrimental effect upon the efficiency of manufacture of products, costs, and lead and delivery times. If this is so, CAD far from enhancing a firm's competitive position (presumably the reason for the investment in CAD) can actually harm it. This outcome would be contrary to the expectation of the literature (Arnold & Senker (1982), Blackburn et.al (1985), Campbell & Warner (1988), Ingham (1989)). Or, second, the ease of modification provided by CAD enabled firms to a) improve the product during its manufacture and b) to take account of changing customer needs. This responsiveness to customers would improve the firm's competitive position. This latter proposition would imply that the balance between cost and benefits of design modifications during production has been changed by CAD. The survey did not indicate which of these two propositions was the case. To clarify this issue structured interviews were undertaken. These used a structured methodology in order to resolve the modifications question. The structured interviews are described in the following two chapters of the thesis.

Further research is required on standard components to determine if CAD increased standard components, or if firms with high numbers of standard components were more likely to use CAD. Again the structured interviews would be used in an attempt to solve this question. Further research is also needed to determine just where the benefits of CAD (and their quantification) occur. Unfortunately, this fell beyond the purview of the research and will be left to other researchers. Once this information is available the implications of using CAD simply for drawing, and the failure to integrate it with production for the competitive position of firms will become clear. Only then will managements be in a position to fully appraise the investment in CAD.

This concludes the first part of the thesis, the national survey, the next part deals with the CAD structured interviews.

CHAPTER 5

Computer-aided Design Structured Interviews

5.1 Introduction

This chapter reports on the results of the structured interviews undertaken to illuminate significant issues of CAD usage. The research design intended that structured interviews of such issues would be undertaken in order to complement the survey results. The structured interviews would provide depth to the survey's generality. It was intended that they should also clarify issues which were determined to be significant. The issues which were determined to be significant were modification and standardisation. On modification it was found that CAD user firms had higher levels of modification during production than CAD non-using firms. The CAD structured interviews were structured to enable the reasons for this to be clarified.

The process of selecting firms for the structured interviews produced the three products of conveyors, machine tools and railway brakes. Fortunately, reasonable size matches in terms of employees and turnover were possible.

The following sections present the write-ups of the CAD structured interviews. Each structured interview follows the same format: company background, manufacturing facilities, market and industry issues, design work, design - production: organisation structure, co-ordination, design process and manufacturing considerations, CAD use, CAD and design for manufacture, computer-aided manufacture and finally analytical issues - modification and standardisation.

5.2 Alpha Conveyors - CAD Structured Interview

5.2.1 Background

Alpha Conveyors are a small company, with 45 employees and a turnover of £2 million pounds, manufacturing conveyor systems for the food and engineering industry. The company have been in their purpose built building (company owned) for ten years. Conveyor systems are produced on a make-to-order basis, with somewhere in the region of 100 to 150 contracts per year. These comprise new systems and some remedial work on installed systems. Systems are thus produced on a one-off basis. Each system is composed of standard lengths of conveyor which are 'cut to length'. The standard lengths, which are determined by the lengths of the raw materials (mild & stainless steel), are manufactured in batches in the required quantities. No lengths are stored as stock. The conveyor technology varies from air force feed for light items such as plastic drink bottles through rollers to ribbed plastic belts, depending upon the packages to be conveyed. The required conveying technology is generally manufactured in house, although, ancillary equipment such as compressors and motors are bought-out.

The typical application is that of plastic drink bottles which have to be conveyed from the blow moulding machine to the filling machine and onto the packaging machinery. These bottles are suspended by a ring around their necks on rails and "conveyed" or propelled by air blowing them along. Principal design problems concern the layout of the conveyor from one machine to another and interfacing with the machine for pick-up and lift-off of the conveyed goods.

5.2.2 Manufacturing Facilities

The company's factory consisted of a large modern "open plan" "shed" approximately 100m by 25m. The factory was laid out from one end to the other, in the following order: raw material store, punching area, bending machine, fabrication stations, assembly and final assembly/ dispatch. Most conveyor systems were assembled in the factory and transported whole, or in modules, to the site. For export, or large systems, the component elements were assembled in threes, in order to check that the complete system could be assembled on site. That is, two component ends were assembled together, a third piece was added to the end of the second and the first piece then removed. This process was repeated until the whole unit had been "assembled". The company employed some 30 manual workers, who were concentrated in the fabrication and assembly areas.

5.2.3 Market and Industry Issues

The market the firm meets is that of food processing companies and engineering companies. The food processing industry form the majority of the firm's customers. Conveyor systems for these customers consist of conveying empty packaging between stations where food is placed in the packaging. The food can either be in solid form, such as, chocolate, or liquid, such as, drink. The conveyors systems the firm manufactures, and installs, are price competitive. In recent years delivery time has also become competitive. Previously, the company was working with delivery times of 10 to 12 weeks, in some cases customers are now demanding four weeks delivery. This is really difficult for the company to meet. Despite its rural location in a non-industrial area the company has a large export market with customers in Australia, South Africa and Europe. This means the company sub-contracts out the packaging of its systems to a local packaging firm. The relationship with this firm is excellent as it has its own expertise in the packaging field.

5.2.4 Design Work

Design work within the company is thus oriented towards the tailoring of standard components to produce a system. Hence, new products, as such, are not introduced. The company do introduce new products in the form of special ancillary equipment - for interfacing with the stations on the conveyor etc. About two such pieces of equipment are introduced per year. This has implications for the questionnaire findings regarding the use of "new product introductions" as a measure of the intensity of design activity of a firm. Alpha conveyors are involved in a high degree of design effort, 100 or so contracts per year, and yet the questionnaire only picks up the introduction of new products as being two per year! Hence, other measures of design intensity must be developed in order to correctly capture the level of design activity within a firm.

5.2.5 Design - Production: Organisation Structure

Alpha conveyors have all three types of design function on site: design, R&D and development departments. There was also a separate production engineering department. The company underwent a reorganisation just over a month after replying to the survey (June 1990). Previous to the reorganisation each of these departments was headed by a manger. This had lead to the build of strong departmental barriers between each of them. This, in combination with the personal characteristics of the individual managers concerned, and their use of the directors to set precedents, caused a great many problems for the company. In particular, it had lost several good engineers through the personal situation that existed between the departmental managers.

The reorganisation of the design and engineering functions of the company produced a structure in which all three functions (design, R&D and production engineering) were under one director. They each had equal status and the personally disagreeable managers had "been shunted out". This had significantly improved the co-ordination and communication between the functions. The degree of co-operation and liaison between the functions has greatly increased since the reorganisation. Each function is thoroughly involved on each contract and its design. The situation after reorganisation could thus be described as a matrix organisation - with missing product lines (these being temporal contracts). More correctly it is an integrated product-process design department.

Lucey (1990) posited, in contradistinction to the normal hypothesis, that personal relations were not an explanatory factor in determining performance. The normal hypothesis is that good personal relations between departments led to good co-operation and performance between departments. Lucey proposed the opposite that good performance led to good personal relations. Therefore, good personal relations were an outcome of good performance and did not determined it. Questioned, as to if the bad personal relations were the result of bad performance of each department the respondent affirmed that the individual personal characteristics of the managers concerned were the cause. Since the managers had gone the situation had radically improved. The respondent, in their case, did not think that good personal relations follow from good departmental performance. This reaffirms the normal hypothesis, this issue, however, will be pursued in later cases.

5.2.6 Design - Production: Co-ordination

Mechanisms for design - production co-ordination within the company primarily took the form of project teams. Product managers were also used from time to time. Meetings also formed a key aspect of design - production co-ordination. Most project teams were not formally constituted, rather a large amount of informal liaison went on. For example, if the design office thought a different material would be better in an application, they would initiate liaison with production and design to ensure that the material was suitable. If production knew the material would be difficult for them to handle, the suggestion would only be taken up if a consensus solution could be reached. This, coupled with the reorganisation, meant the company had a high degree of design - production co-ordination, described as very good on the questionnaire and in person. A fundamental element in this achievement was the weekly production meetings. At these meetings design engineers, managers, production engineering, sales, production and R&D personnel attend to discuss the progress of current and completed contracts (ie. those requiring remedial work or customer initiated modifications). This ensured that production and production engineering had a high degree of influence on the design of the contract.

5.2.7 Design Process and Manufacturing Considerations

The questionnaire survey investigated the stages during the design process when various design aspects were considered. Alpha conveyors only considered two aspects in the conception stage, product cost and engineering design. During the detailed design phase the design aspects of functional requirements, engineering design and standardisation were considered. The only production aspects considered during this phase were materials, existing products and production control. During the next phase, prototype/ testing, styling and assembly techniques were considered. This latter is what would be expected from a company conforming to the norm - obviously one considers how to assembly the product when it comes to building the prototype. The remaining aspects, all production, were considered during pre-production. The respondent did not see any need for these to be moved forward to earlier in the design process. The respondent argued that the context of the individual firm will determine if it is necessary to consider some aspects earlier or later in the design process. Thus, due to the standardised nature of the product and its assembly the firm found it unnecessary to consider assembly techniques early on in the design process. On the other hand it is more appropriate for the firm to consider standardisation, materials and existing products early on in the design process to see which components already in production can be included in the new design.

5.2.8 CAD Use

The company uses a CAD system to draw the layout of the conveyor system, the rest of the design work is done in the drawing office. They also use a CAD system for the electrical layouts but this is of no concern here. All design work is carried out to customer specification, with negotiation over details which would more suit Alpha Conveyors. Increasingly customers are supplying their layout drawings to Alpha Conveyors via CAD - using AutoCAD. For this reason, and the lack of accuracy on their first CAD system, an AutoCAD package running on an Apricot PC was purchased in early 1990. Use of AutoCAD means disks can simply be exchanged from the customers to Alpha and back again when design work is complete. This eliminates the problems inherent in incompatibility of differing CAD systems and in translating drawings from one system to another.

The company have decided to further invest in CAD by purchasing two further PC workstations (386 based) again running AutoCAD. This represents an investment of some £25,000. The drawing office manager had produced a capital bid and figures to justify it. This was first of all halved by the board, however, in the end the full amount was approved. One work station will replace the current work station in the design office, the old machine being placed in the sales office for interaction with customers. The second system will be installed in the drawing office and will be used to soak up the remaining layout work still done in the drawing office. The future plans of the company include the intention to purchase more work stations in order to have all eight drafters with their own work stations.

Training was a concern of the company. All the operatives who would be expected to use the CAD system had attended an 8 week AutoCAD course at the nearby college. Three people had been selected to attend the City & Guilds CAD course. These courses were attended in the employees' own time during the evening. It was hoped that this training would enable the operators to effectively use the system. It was not seen as necessary to appoint a CAD manager to be responsible for the CAD design work. Thus, the management and archiving of drawings would be left to individuals.

5.2.9 CAD and Design for Manufacture

The aims of the research included considering if CAD had led to a greater effort on the part of firms to design their products for manufacture. As indicated earlier the CAD system was used to produce the layout drawings of the conveyor system. The company had ticked the "Component Interference Checking" and "Design for Assembly" boxes on the questionnaire. What they meant by this was not that the CAD system automatically checked these things, but, that the CAD system was used manually to check for interference and correct assembly. This explains the high score for component interference checking measured by the survey, 40%:

Firms were using the CAD system to aid the manual checking for interference but not doing it automatically. Hence, although CAD was not automatically checking for interference and aiding design for assembly it had aided the manual process of performing these tasks.

A further issue in aiding design for manufacture is if the production engineering personnel have access to the CAD system, preferably to change designs. At the present time, with the single system, the company did not allow production engineering access to the CAD system. This was because the CAD was fully utilised in layout preparation and there was no free time to allow production engineering to use it. It was intended when the new systems came in to allow production engineering access to them.

5.2.10 Computer-aided Manufacture

CAD can greatly aid the bridging of the design - production interface by being linked to CNC machines. In the company the CNC consisted of punch machines for punching the steel blanks. Drawings were passed on disk to the planning department who programmed the CNC machines. Asked whether the company had considered networking the new CAD systems the reply came that they had better learn to walk before running!

The benefits that the company had achieved with the CAD system covered not only the ease of modification and rapidity of design benefits expected but also shortened lead times, shorter production runs, greater customisation and increased consideration given to manufacture. This latter was the ability to check if things assemble correctly before manufacture. The greater customisation had meant they were more able, through the use of CAD, to tailor standard designs/ components to customer's requirements. This and the rapidity of design had enabled the company to reduce the needed runs of components and thus meet smaller orders.

5.2.11 Analytical Issues

The primary purpose of carrying out the structured interviews of firms using CAD was to identify reasons for the preponderance of them to have higher modifications than none CAD users. Alpha Conveyors were low (0-10%) on modification. The reasons for this were the standard nature of their product. Each conveyor system was made up of standard components, the process of manufacturing these was well understood. The modifications that did arise, arose either from production changes or from customer initiated changes. The customer initiated changes were by far the largest cause of the modifications made during production.

As to whether the greater standardisation of components had enabled the company to easily adopt CAD the response was negative. The primary motive for CAD adoption was the benefits it provided, rather than the highly standard nature of the product. CAD also had not, as yet, led to a greater standardisation of the product.

5.3 Beta Conveyors - CAD Structured Interview

5.3.1 Background

Beta Conveyors are a small family owned concern, with 40 employees and a turnover of two million pounds, manufacturing conveyor systems for waste disposal and recycling applications. They have been at their present site for 40 years. Once again the conveyor systems are made to order and designed individually for each application. The design effort is concentrated on new systems with any redesign work being charged for. Each system is comprised of differing lengths of conveyor which feed the conveyed material from one location to another. The conveyor lengths have not been standardised by the company and each system is designed from scratch. Neither can the firm build up libraries of standard parts due to the differences between systems. The materials carried tend to be heavy and thus the conveyor technology varies from plastic or rubber chains or belts (generally bought-out) to steel rollers or chains (which are made in-house). The ancillary equipment, such as motors is bought-out, although at one time they were made in-house.

The typical application, if there is such a thing, consists of a conveyor for waste paper in a paper recycling plant. Here, the principal design problems concern the layout of the conveyor and the conveyor technology for propelling the conveyed material. The conveying of heavier wastes poses more serious design problems involving a lot of design work.

5.3.2 Manufacturing Facilities

The company's factory consisted of a small to medium sized industrial unit that was divided by partitions into sections. The two main sections were fabrication and assembly. As much assembly work as possible was carried out on site, due to the expense of on-site assembly. A good deal of on-site assembly could be necessitated for the larger conveyors, however, everything was preassembled in sections in order to check that the final system was assemblable. The manual employees were concentrated in the fabrication and assembly areas.

5.3.3 Market and Industry Issues

The market the firm meets is the somewhat diverse waste disposal and recycling industry. Conveyor systems for these customers consist of carrying paper and other waste from silos, and or lorries, into and around customer's disposal or recycling plants. The firm has chosen to supply the high end of the market with quality bespoke systems. Price is sensitive and the firm has lost orders on this basis alone. Delivery time is not so sensitive.

5.3.4 Design Work

Design work within the company is oriented towards the design of one-off, or bespoke, conveyor systems. Again very little design work is for new products. Only one new product per year is introduced and this is usually a piece of ancillary equipment for a special application. This again shows the inadequacy of using the number of new products introduced as a measure of design work.

5.3.5 Design - Production: Organisation Structure

Beta Conveyors have organised their design function as an integrated product-process design department. This is headed by the Technical Manager under whom are the Drawing Office Manager and the Production Manager. This provided for good communication between the design and production functions within the firm.

5.3.6 Design - Production: Co-ordination

Within the integrated product-process design department there are six project engineers who are placed in charge of individual contracts. These engineers act as product manager/ champions for each of the contracts they are responsible for. They oversaw the design and manufacture of each contract, raising drawing office and factory requests as necessary. Monthly co-ordination meetings of these engineers, the firm's directors and production management are held to review progress and problems on contracts. The firm also adheres to BS 5750. This entails the division of the design process into stages at which checklists are ticked. It also ensures documentation of the design is produced and that control of the design process is easy to attain. Crucial here is the documentation and design review meetings. Also non-conformance reports and engineering change notices are implemented by the firm for the control of amendments and modifications to designs. The company has procedure manuals for its design process. These were compiled by consultants who were paid for by a Department of Trade and Industry grant.

5.3.7 Design Process

In contrast to Alpha Conveyors the firm had brought forward the consideration of many aspects in the design process. Thus, Alpha only considered product cost and engineering design in the conception design stage, whereas Beta also considered development costs, labour requirements and materials. This difference is accounted for by the lack of standardisation of Beta's product and their small size. They would obviously have to consider for each contract early on whether it was worthwhile investing in development and whether they had enough employees of the right skill to efficiently manufacture it. The non-standard nature of their product was indicated by their none consideration of existing products during the design process. Beta also brought forward the consideration of most production aspects (production processes, plant and machinery) into the detailed design phase, whereas Alpha only considered these in pre-production. Hence, the hypothesis that earlier consideration of production aspects in the design process would lead to better design performance, in terms of lower modification, for this firm was not confirmed. Rather, the non-standard nature of the product meant that the firm had to consider these aspects earlier on instead of waiting till the latter stages of the design process.

5.3.8 CAD Use

Beta Conveyors have been using PC CAD systems since 1985. These have been added to at the rate of one a year to bring the complement up to five. These five systems all run an early CAD package RoboCAD. This is a simple and easy to use program. In April 1990 the firm bought an AutoCAD system. The firm are hoping to move to a network so as to electronically interface with the computerised MRP II production control system. They would not do this until the performance of the MRP II system had improved and until they had been able to effectively use the bill of materials feature of AutoCAD. Beta Conveyors also exchange drawings with their customers, but unlike Alpha this was not via disks. Further, they had not found it necessary to adopt one particular CAD system which was used by their customers.

Nearly all design work in the firm is done on the CAD system. Training has not been an issue for the firm due to the simplicity of the RoboCAD package. The company have found it an easy to use package which can be learnt fairly rapidly through using it.

5.3.9 CAD and Design for Manufacture

As regards CAD helping design for manufacture the firm said that CAD had helped. This occurred through CAD formalising ones mind, concentrating it on a design and on its manufacture. CAD also was forcing the company to standardise its designs and move towards the use of standard components. Other benefits of CAD included its accuracy and its rapidity of design for simple components. With more complex components CAD could take as long as using a drawing board. CAD also had the benefit of getting people more computer familiar, such that they would be amenable to computer use throughout the company. CAD had only shortened the lead time for product introduction if the design was only a modification of an existing one. This happened extremely rarely in the firm to be of any gain. CAD had not enabled the firm to increase the sophistication of its product but it had been able to more easily customise the design to suit the individual customer's needs.

Production engineering did not, at the moment, have access to the CAD system but when the network was installed they would have access to designs. The CAD system could be used by the project engineers for the preparation of quotes for customers. The company were not using the CAD system for anything other than drawing, they were intending to link in electronically with an MRP II system in the future.

5.3.10 Computer-aided Manufacture

The company only had one CNC machine - a folding machine. This was manually programmed by the production engineers. The other computer-aided manufacture system the firm had was an MRP II system for production control and scheduling. It was intended that with the use of AutoCAD and finally the network that bills of material could be compiled electronically and fed into the MRP II system. As is well known with these systems the firm had a lot of trouble with it and were not able to use it to its full extent. The company were still manually scheduling some things and overriding the computer produced schedules.

5.3.11 Analytical Issues

Modifications for Beta Conveyors were high 21-30%. The modifications which occurred during production were due to two sources either customer initiated changes to the design or modifications necessary to manufacture the system. The modifications that were made were due to the non-standard nature of the product and the particular problems that each design posed during manufacture.

The company did not have standards. The reasons for this can be deduced to be the small size of the firm and the non-standard nature of the product. Each conveyor system was unique and required individual design. Component standards were also difficult to implement, as for example electric motors which had to have different power rating depending upon the conveyed material. Thus, the scope for standardisation was low.

5.4 Delta Machine Tools - CAD Structured Interview

5.4.1 Background

Delta Machine Tools is a medium sized firm, employing 540 with a turnover of £25m, which is part of a foreign owned multinational. The company has been long established in this country and occupies modern post World War Two buildings on its original site. The company produces a wide range of machine tools, mostly milling machines and machining centres, for the engineering industry. These are all nowadays computer controlled. The machines are made to the companies own design, although some machines are produced from the parent company's designs. The company manufacturers two types of machines - standard and specials. Standard machines are used to form a range of machines. Each machine in the range is a variant of the basic machine, hence the name standard. Specials are standard machines which are put together for specific customer applications. For example, a line of five milling machines connected together with AGVs (Automatic Guided Vehicles) or rail track vehicles, for a customer producing engine blocks. Thus, for specials standard machines are used with the special part deriving from the connecting hardware (AGV or rail etc.) and associated control equipment.

The company produce a wide range of machine tools, principally horizontal and vertical milling machines, but also lathes. Some machines, such as the large vertical column machine are designed for large work pieces (10m in length) and hence the tool does most of the movement.

5.4.2 Manufacturing Facilities

The company only carries out two manufacturing processes themselves - machining and final assembly. All the fabrication work (of large cast components and steel fabrications) is subcontracted out. The factory is divided into three parts. The machine shop where final machining of the bought-out fabrications is carried out. The final assembly area where the machine tools are assembled and lastly the paint shop. The machine shop is located in a large "shed". Most of the machines in it are traditional machine tools - company produced and non-company produced. The company have, over the last year (datum 1990), been implementing FMS machining centres, "cells". Two are presently in operation with a third under construction. These are interlinked with AGVs. The new cell will be linked with rail vehicles, as it was found this is cheaper than AGVs. The final assembly shop is also located in a large shed. Machines are assembled singly in cells, after which they are sent to the paint/dispatch area.

5.4.3 Market and Industry Issues

Machines are made to order, in the hope to hold no final stock. In the current (1990) economic climate this is proving difficult to achieve and one or two machines are, therefore, having to be held as stock. The company, as the British subsidiary of a US parent, both sells its own machines and acts as an agent for the US parent. The US parent also acts as an agent for the British company. The company thus sells to the domestic and European markets on its own account and to the US through the parent. Since 1980, due to the current recession, the company is not manufacturing as many machine tools per week as it would like. The introduction of new machines, particularly sophisticated and expensive ones, is quite a risk for the company. The company have thus moved to produce simpler machines in larger production runs. Over the last five years the company has also experienced tough competition from Japanese and Korean machine tool manufacturers. This has necessitated the company shortening the lead times for the introduction of new machines. It has also brought about a greater use of bought-out components and a radical slimming down of internal manufacturing. The company has thus moved from hierarchy to market in its overall operation (Williamson, 1975; see Riedel, Lewis & Pawar, 1991 for an elaboration of the strategic issues involved).

5.4.4 Design Work

Design work within the company is tailored to the production of the design of machines to fit into a product line, or range, of machine tools. The introduction of new lines of machine tools occurs infrequently about once a year. However, in order to fill out the range of machines each individual machine must be designed. Thus, a reasonable amount of design work is engaged in. This, again, as with the other structured interviews shows the inadequacy of new product introductions as a measure of the amount of design work undertaken.

5.4.5 Design - Production: Organisation Structure

The design/engineering and production functions within the company are headed up by two different board directors. The design engineering function is located in its own open plan office, and was headed by two engineering managers. The production engineering, including the CNC programmers are located in a separate office below the design office. Within the design/ engineering office work is further divided. As mentioned above, the company produces two types of machines - standard and special - an engineering manager is responsible for each type of design. There are also three types of design activity within the design office. First, mechanical design, second electrical and third software design. These latter engineers are responsible for writing the software to interface the machine tools to the controllers. The company has a labour retention problem with these software engineers.

5.4.6 Design - Production: Co-ordination

The company, since 1986, have adopted project management as a management technique for application across the company. Co-ordination for the introduction of a new machine is achieved through two mechanisms. First, a project manager is appointed to oversee its introduction. The project manager is supplemented by a multidisciplinary project team. This team is made up of engineering, manufacture (make and assembly), purchasing, service, shopfloor supervision, sales, marketing and finance (for machine cost). These people attend the project team meetings on a regular basis. The company has three project teams in operation: standard machines, special machines and internal projects (for the new FMS cells and new MRP II system). Second, the company holds design review meetings. These occur between members of the design and manufacturing functions. They are held regularly and are designed to attune the design to make it easier and more efficient to manufacture. The manufacturing function also have a definite veto over the design.

When asked about departmental barriers being a problem the company replied that these are inevitable. Designers are thinkers:- they think they know best; they cannot be told what to do. Manufacturing have high expectations which will not be matched:- the manufacturing engineer will not get just what he wanted. This barrier can only be broken down by getting people to sit down next to each other and to talk. And then coming up with a compromise. This is the most difficult part of the project to get over. Physical proximity was a help in reducing the barrier. Even then there is a perceptible departmental barrier between the electrical and mechanical engineers located in the same office. Organisational politics also come into it. Do you get rid of the head of engineering and/or head of manufacturing, or even the respective directors! Personal relations were not a problem in the company. Although, rude words were used in meetings people had the good sense not to carrying them outside of the work context and to remain friends. What compounded personal and political problems was the fact that the project management meetings were carried out at managerial level. At this level there are bound to be differences and disagreements. This was less of a problem at the design review meetings.

5.4.7 Design Process and Manufacturing Considerations

Delta machine tool were very good in considering manufacturing considerations early on in the design process. Standardisation, production processes, plant, machinery, assembly techniques, materials, and existing products were all considered in the detailed design phase. Labour requirements were considered in the conception stage. Only production control was considered "late" in the prototype stage. Part of the reason for this early consideration was the necessity to get approval from the US parent for the introduction of a new standard machine. This meant documentation, in the form of specifications for the machine, intended market, project and machine cost and margins, had to be produced. Also some proposed layouts and assembly drawings were produced. This forced the company to consider manufacturing aspects early on, during the detailed design phase, and not leave it until the design was transferred to production.

5.4.8 CAD Use

The company have a large CAD/CAM system. This runs on an IBM mainframe computer. The system was purchased in 1983 and was compatible with the parent's CAD computer. Originally eight screens were located in the design department with one in the CNC programming office. The system worked well - the computer power was adequate and the drafters were able to make effective use of it. The company did try to use three PC systems but found problems (lost work and files) and they scrapped them. The company now have 15 terminals, 12 in the design office and three in the CNC area. At the present time the mainframe also runs the wages, MRP and CAD all at once. This has created some problems, noticeably slow response times at the terminals. The company are purchasing a new mainframe which will take over the wages and MRP systems. This will leave the CAD plenty of room on the first computer. The company would like more terminals but the problem is to justify them. The original CAD hardware (terminals and plotter) cost three quarters of a million pounds. The company obtained a government grant to subsidise this cost. The maintenance costs of the terminals are also high. This accounts for a large chunk of the design office's budget. The hardware and software maintenance costs of the mainframe are met centrally.

The company trained all the CAD operatives in house. All drafters were trained to use the CAD system. This consists of two weeks being trained to use the system. Two months probation - doing simpler jobs under a mentor. After six months operators have reached the same rate as the experienced users. The CAD system did not change the way the company used people. Everybody does all of their own job, whether it be bill of materials, assembly or layout drawings. The company, therefore, do not have detailers. This may have been a mistake as they could have got more work from detailers. The twelve CAD terminals are shared by 30 drawing office personnel. Of course, the company want more but they have to justify them. A booking system was used to book time on the terminals. This can hold up work and if work is urgent it is done on the boards. What really holds up progress, though, is the breakdown of the plotter. A further difficulty is that the occupancy of terminals cannot be planned. The company, hence, used subcontract design firms to do work and also employed contract staff. All subcontract work is done on paper as the subcontractor firms cannot afford such expensive CAD hardware as the company. There was no specific manager appointed to run the CAD system. One of the two engineering managers had responsibility for it.

When the CAD system was installed only new designs of standard machines were transferred onto it. At first special work was done on paper, as all the old drawings were on paper. Now specials are also done on CAD. Nearly all the machines currently in production are now on the CAD system. There are no specific drawings which are done on the CAD system or on paper. The decision is based on other criteria, such as work load etc. Asked whether there was a need to design in 3D the company replied that the design process does not require 3D. They would also need to change the complete design process. They would also require the money to invest in a 3D system.

5.4.9 CAD and Design for Manufacture

Here the effect of CAD on design for manufacture will be discussed. Delta machine tools had also ticked the Component Interference Checking and Design for Assembly boxes on the questionnaire. However, as with the other structured interview firms they did not mean that they used special programs on the CAD system to perform these operations. The only automatic procedure that was of use was tolerance checking. Delta had improved its design for assembly through CAD use by being more able to make design changes quickly. The ability to produce new versions of designs quickly had led to better design, as changes were easier to make and rapid. Thus, the chain of design drawings from layout, detail to final assembly, and the improvement due to easy and rapidity of change, had led to fewer mistakes on the shopfloor. In fact the increased confidence that the firm had in its design methods had allowed it to scrap a machine design it was not satisfied with and start again as they thought they could do it better. Previously, they would never have thought of this because, on paper it would have taken too long. CAD had thus enabled the firm to shorten the time taken to design a new machine.

The company also used finite element analysis to improve the design of the bed of the machine. This was done by sending the data to a specialist team at the US parent and waiting for the results to be sent back. The benefits of doing this were ambiguous. First, performing the finite element analysis added a time delay to the design. Second, the cost saving on material had to be balanced against trying to get down the assembly cost during fabrication. Material cost could be saved by reducing weight and increasing the number of ribs. The correct amount of material was achieved when the design had the necessary amount of stiffness to support the cradle or saddle of the machine. This obviously involved a lot of fine tuning of the design which added delays. The material cost saving produced was not significant. The savings of cost of fabrication were more significant. Further, attempts at material saving through increasing the number of ribs complicate fabrication and thus add to this cost. The company thus choose to minimise the cost of fabrication.

Asked whether CAD (and CAM) had acted as a bridge between design and manufacture the company replied that the bridge arose more from the management team than from CAD. In order to achieve this there was a need to sit people (design and production) together. This could only be done after the details had been drawn. Second, there was the problem of organising time to physically get people to sit together - people were off sick, on holiday etc. The details were sent to manufacturing - who produced route sheets to see if they could make the part, and to purchasing to make the make or buy decision. The trend within the company was to buy in parts rather than manufacture them in house. Their latest machine only had 73 in house manufactured parts, the rest were bought-out.

The company had also improved its performance on lead times. It had reduced the lead times on the last three new machines it had introduced. This, however, was not due to CAD. CAD had helped reduce the up-front time (design time before pre-production). The real improvement had come about due to three factors. First, basing new designs on current machines, thus producing families of machines. The first machine so introduced was started in Whitsun and completed the following

January (seven months). The company had never done a new design so fast. A further two machines were also introduced in a similar time. The second factor was the project team management. The problem with this approach was that the company did not have enough people for teams, especially now in the recession. The third factor was organising suppliers and internal manufacture to deliver parts when needed, and quicker than before. Internally, the use of FMS seven days a week had helped to shorten lead times.

The company had also been forced to pay greater attention to manufacture of the product due to the increase in competition from Japanese manufacturers. This, attention to manufacture, however, was largely in the gift of the designer. That is, in the head of the designer. When detailing a part, could the designer see that if a change were made would the part be easier to manufacture?

5.4.10 Computer-aided Manufacture

Delta Machine Tools also ran a CAM system on the CAD mainframe. They ran two separate systems. One for prismatic parts and one for turned parts. The latter was developed in-house by the US parent company. The use of CAM had increased over the years and was intended to increase further. The company was increasing the use of FMS machining cells.

5.4.11 Analytical Issues

Here the two issues which the structured interviews were designed to clarify will be discussed. First, design modifications after drawing transfer to production. On the questionnaire the company had indicated a low amount of modification: 0-10%. At the prototype stage the company expected a reasonable amount of change: if it does not fit, not easy to assemble or can be done better. When a design is in production changes are rolled up to every six months for implementation. These modifications are either new features or maintenance changes. The design review vetting procedure and the prototype stage were used to reduce the number of modifications during manufacture. Design changes and changes to fixtures were all attempted to be done before the machine went into real production. Delta were moving toward larger production runs of machines. For example, of the new small vertical machine ten a week were produced. This meant a greater restriction of change as a hiccough would cost more than the saving (of the effect of the change).

Second, on the issue of whether CAD had increased the amount of standardisation the company said that they were always very good but that CAD was a big assistance in standardisation. The company had ticked the 81-100% standardisation box on the questionnaire. This high degree of standardisation had helped the company reduce the up-front, or design, time of new machines. The high degree of standardisation in the company was not the reason for the adoption of CAD. However, CAD was of more use to highly standardised firms and therefore to us (Delta).

5.5 Theta Railway Brakes - CAD Structured Interview

5.5.1 Background

Theta Railway Brake are a medium sized company, with 650 employees and a turnover of £31 million pounds, manufacturing railway braking systems. The company have been on the same group site for roughly 150 years. They thus share buildings which are widely spread out with other companies in the same group. The company is owned by a UK large engineering company. Railway braking systems are produced to contract. Each contract means a redesign of the braking systems offered by the firm. Secondly, the life span of these systems, some thirty years, means that spare parts for old designs have also to be produced. The braking systems are pneumatic and as well as fulfilling the individual customer's performance specification have to be fitted into a pre-allocated space on the train. Each system is comprised of a number of standard components, such as pneumatic valves and reservoirs, which have to be redesigned for each system. Standard components are thus not made to stock, each contract being made to order, with components made in batches.

5.5.2 Manufacturing Facilities

Theta Railway Brake manufactured a diverse range of components: pneumatic, electrical, mechanical, vacuum and hydraulic. The company have a large and diverse manufacturing facility. This consists of separate workshops for fabrication, plumbing, wiring, final assembly, test, various component assembly shops and raw material and bought-out stores. The machine shop consists mostly of traditional machines: shapers, lathes, milling machines, drills etc. and three Hitachi Seiko CNC machining centres. The Hitachi machines are very sophisticated machines having a 200 tool changer, 10 palette work-piece changer and are directly controlled by a DNC microprocessor. The loading of component programs into the machines is controlled by the operators at the DNC console. Alterations to the machining programs can be made by the operator. A procedure whereby the alterations are approved by the CNC programmers must be adhered to before the changed programs can be used by the operators again.

5.5.3 Market and Industry Issues

The company's main market was domestic, consisting of British Rail and the other railway vehicle manufacturers eg. MetroCammel Weyman. The latter involvement brought the firm export business. This complicated the design by requiring the company to conform to differing national standards. The company have tried to enter the European market but have encountered insurmountable barriers in France and Germany. Both price and delivery are sensitive. The company has loss-led on contracts in order to secure future business with a customer.

5.5.4 Design Work

Design work within the company is geared to the one-off design of each braking system contracted for. This consists of the design to meet the customer's performance specification and the physical layout of the system in the space allocated by the customer. Thus, although each system is made up using a well understood technology and components, each system is sufficiently different to warrant significant design from scratch. Again attempting to measure the amount of design activity by the number of new product introductions was incorrect. Three or four completely new products, such as air compressors, were introduced per year. Fifty variants of existing designs were also produced per year. These were on top of the design effort for each contract. The number of contracts per year was about 100 to 150. Thus the design activity was quite intensive. It also varied according to the number of contracts the firm was processing simultaneously. They would easily employ contract drafters within their drawing office. At the time of the research they had also sub-contracted work to three external design-drawing offices.

5.5.5 Design - Production: Organisation Structure

The company underwent a reorganisation in 1988 (two years before the interview) which placed all the departments of the company from commercial to design into one large open plan office. Previous to this these departments were variously located in different buildings. This caused a good many liaison problems which the new arrangement overcame, communication was now said to be good. The company had design, development and R&D departments on site. These latter two were quite small compared to the design department The Contracts/Engineering department were responsible for the management of contracts. Departments were set up as a matrix organisation. The production engineering department had, however, been moved out of the design office space and located in the machine shop by the reorganisation. This was because it was felt that they were more concerned with the machine shopfloor. This separation had created liaison problems. Designers would go and visit them informally as necessary. Also the comprehensive standards manuals helped - defining even screw sizes and the like.

5.5.6 Design - Production: Co-ordination

For the co-ordination between design and production the company occasionally used project teams, then product managers and most importantly ad-hoc consultation. The Contracts department organised regular review meetings. Design had generally good relations with the, physically distant, production engineers. It was found that attempts to consult the CNC machine planning/ program engineers early in the design process were ineffectual in improving design for manufacture. This was due to two reasons. If a drawing was shown to them early on they were too busy with the current production concerns to give it enough attention. Second, the attention they gave it was insufficient, they would only really check that it was correct and easy to manufacture when the drawing was handed over for actual programming. This has similar implications for other firms with separate design and programming departments who wish to shorten lead-times to production.

The drawing office itself had itself undergone a reorganisation in May of 1990 (six months before the interview). Previous to the reorganisation there was a flat structure, with everyone of equal status. Each individual drafter worked on the job centrally allocated to them. This had led to morale problems and problems with authority: no one knew who was in charge of which contract and, therefore, did not know whom to approach for advice on a design. This was changed into drafters being organised into groups of two to four, under a senior designer. Thus, each drafter reported to the head of group and could identify with the work of the group. This is the classic rationale behind Autonomous Work Groups (AWGs: Kelly, JE & Clegg, CW. 1982). Drafters could, however, be moved from one group to another, or work on other contracts/ jobs, as dictated by the workload.

5.5.7 Design Process and Manufacturing Considerations

Theta Railway Brake only considered two production aspects during the conception design stage: standardisation and existing products. With the exception of labour requirements the other production aspects were considered, early, in the detail design stage. All the production aspects bar standardisation and existing products were reconsidered in the pre-production and production stages. Design aspects, functional requirements and engineering design, were considered in the first two stages. Thus the company attempted to consider as many production aspects as early as possible. The caveats discussed above of early involvement also apply. A major difficulty for the company was the fact that products were not developed prior to manufacture. This made it harder to incorporate design changes prior to manufacture.

5.5.8 CAD Use

Theta Railway Brake have had a large CAD/CAM system since 1985. This is based on a Prime supermini computer. This large host computer was originally used as the business system computer by Theta, however, when it became too small for this task it was "pushed" onto the CAD manager. The main disadvantage of the system is its running costs. Hardware maintenance and software usage charges are higher than if a smaller system more appropriate to the department's needs were in use. The system runs Prime's Medusa CAD package and the CAD Centre's GNC package for CNC programming. There are five colour CAM terminals located in the production engineering section, with a further three alphanumeric terminals, for programming work. The CAD department have six black and white terminals and one colour terminal. At the time of the original investment in terminals it was decided to have six black and white terminals rather than just three colour ones. Theta have just acquired a further two colour terminals. The justification for the extra investment came from the 30% saving in the CNC programmers not having to manually enter the geometry by electronically transferring drawings. That is, the justification was based on a saving not accruing from the CAD system itself and its use.

The rest of the drawing office consisted of ten or so drawing boards. The more inexperienced CAD operators tended to do more detail work and thus spent nearly all of their time at the terminals. The more experienced designers would alternate from one to the other. Partly, this was because they had more confidence in correctly positioning a drawing on the paper first time round.

The criteria for deciding as to whether a drawing was to be done on the CAD system did not rest on its complexity, rather the following factors were considered. Drawings would be done on the CAD system; if they were similar, if it was anticipated a brand new design would be in use for a few years hence, if there was a high machining content (beneficial due to the direct link with CAM). Welding, fabrication and assembly drawings tended to be done on the drawing board. A major criterion was the workload at the time. Further, some things were easier on the drawing board. Conceptual design work was easier with pencil and paper and pipework due to the need to see an overall view of the layout, rather than zoom views, were easier. Also altered, or modified, designs were easier by hand where the tracing section could use film and manual cutting and pasting of film to produce modified drawings rapidly.

Due to the long life of designs within the firm, and the need to supply components and improvements to designs in service over thirty years, drawing management was a problem. Old drawings had not been entered on the CAD system, and there was no intention of so doing (given the number involved it would be ill-advised). A database of previously existing designs did not exist. At present the CAD system was not able to track drawings in a library type arrangement, only the individual drawing files existed. No drawing documentation (such as the title block data) was stored in an archive or database. A manual card index system existed which, given the lack of data recorded and the lack of cross referencing (by part name/ number, contract number etc.), was pretty inefficient at locating drawings. This also meant that parts lists, or better bills of material, were not stored or processed by the CAD system. Parts lists were entered by the production engineering staff manually onto the business system computer (which was linked electronically to the CAD computer). These lists nearly approached full bills of material. Designers only have access to these through a single terminal in their section.

Training had also not been an issue in Theta Railway Brakes. The CAD/CAM manager had been on Prime Medusa courses but found these of little use. The CAD/CAM manager had trained up all the operatives in the use of the system. He also attended the Medusa user group which was much more useful in getting to know how to use the system effectively. The CAD/CAM manager, as well as carrying out some design work himself, had to carry out the system manager function for the computer system. This entailed writing job control programs, monitoring the CAM transactions and modifications and installing new releases of software etc. The drawings produced by the external drawing contractors were transferred onto the Prime using the IGES translation standard. The company were happy with this given the problems that can be experienced with IGES, as they only needed the shape and geometry - the dimension accuracy was not needed.

5.5.9 CAD and Design for Manufacture

The biggest benefit of the CAD system was quality, of drawings and also of designs. The benefit of ease of modification was double-edged, as the time taken to change drawings was a cost. CAD also allowed a flexibility in design which was not possible using drawing boards. Generally CAD was quicker for producing drawings, but some things can take longer on CAD. Standard drawings and drawings using parametric design were very quick to produce on CAD.

Due to the possession of the Hitachi DNC machines the company had changed its business and design policy. Pneumatic interconnections are problematic. If piping is used for the interconnections it is expensive both in design and in assembly time and labour. The company, therefore, replaced physically close interconnections with solid aluminium blocks (aluminium to save weight). Previously, these were sub-contracted out for manufacture (precision casting). The Hitachi machines made it cost effective to machine solid blocks of aluminium into the correct shapes. The firm had thus made the business decision not to invest in precision casting equipment (Aluminium is a difficult metal to cast due to porosity and cavities). The solid blocks were also easier to design than piping layouts. More importantly, the direct link from CAD to CAM for the production of these blocks made it very cost effective. Therefore, in designing the pneumatics these block were used as much as possible (long interconnections still have to be made with pipe).

5.5.10 Computer-aided Manufacture

The firm's CAM equipment was very advanced, it was also well integrated with the CAD system. This link between CAD and CAM was difficult to establish initially and involved a lot of effort in concert with the suppliers to achieve. The main problem was the transfer of the drawing and geometry to the GNC CAM package. These problems were overcome to the satisfaction of the company.

The microprocessor based DNC system had also involved considerable effort to establish, but had provided four main benefits. First, unattended operation of the machine tools. Second, allowing and controlling, machine operator alterations to CNC programs. Third, it had provided for 24 hour operation of the machines. Finally, a microprocessor backup unit meant CAD and CAM files were always up to date and should the Prime main computer go down CNC operations would continue. The advanced nature of the CAD - CAM link in the firm had enabled them to achieve great benefits in design for manufacture.

5.5.11 Analytical Issues

As mentioned above a major difficulty for the company was the fact that products were not developed prior to manufacture. This was due to there being no time or money to spend on development. This, of course, led to problems in production, assembly and testing. In combination with the non-standard nature of the product it obviously led to a great deal of design modification during manufacture, reported on the questionnaire as 51-70%. Some of these modifications were due to customers' demands. A major source was the need to meet delivery times. This forced the company to manufacture earlier than should be the case, ie. before the necessary development work had been carried out. The company did admit, however, that they themselves took a little too long in getting designs into production. All of these factors, lack of development, nonstandard products and the need to meet delivery dates led to the high degree of modification during production. The company was not complacent about this. They had recently set up a task force headed by Lucas Consultants. This task force, apart from looking at the performance of the company's overall operations, was investigating the design process and specifically improving design for manufacture. The task force had costed modifications at a quarter of a million pounds per annum and was investigating why they occur.

The company had a comprehensive standardisation system in operation. BS 5750 approval was achieved very easily due to the standards, procedure and reviews the company already had in place. The company had standards for "standard" components such as screws, compressors, motors, pipes, joints. Also manufacturing standards for assembly, and wiring etc. were included. Some of this effort was necessitated by the safety considerations of the railway braking systems the firm manufactured as well as being indicative of good practice. The non-standard nature of the product meant that product level design standards were not possible. Even some components were not possible to standardise.

5.6 Upsilon Railway Brake - CAD Structured Interview

5.6.1 Background

Upsilon Railway Brake are a medium sized firm, of 260 employees and a turnover of £20 million pounds, manufacturing railway braking systems. The company was established about a hundred years ago. It occupies several older brick buildings for offices and seven post-war sheds for manufacture. Braking systems are produced on a make-to-order basis with roughly one contract in progress per year. The company also supply pneumatic control equipment on an ad-hoc basis to customers who approach them. The company is owned by Thyssen of Germany with the original English family owners both sitting on the board and running the firm. As with Theta Railway Brake, each system means a redesign of the company's braking systems to produce a customised piece of kit not sold to anyone else. The redesign is both to meet the performance specification and the space allocation of the customer. Each system is comprised of standard components, pneumatic valves, reservoirs, compressors and electronic control systems. These latter and the associated operator controls give rise to the greatest design changes. Again components are made to order in batches as required and not held in stock.

5.6.2 Manufacturing Facilities

Upsilon Railway Brake also manufacture a diverse range of components. They produce approximately 900 different valves. Each of these may have up to 20 different variants. Compressors also have many variants. The company's manufacturing facilities are spread out over seven sheds. They consist of several machine shops, mostly using conventional machine tools. One shop has three DNC controlled CNC machining centres. The programs for these can be modified by the operators. Only two of the machines can send the modified program back to the DNC controller. Unlike Theta there is no approval procedure for these changes. There is also a large component assembly shop and a smaller final assembly shop. Components and sub-assemblies are tested after assembly and, therefore, there is no testing shop. (This makes the assembly shop look cluttered.) The dispatch area is located away from the assembly shop due to restrictions of the site. Most components are made in-house. Even the electronic control systems are made in-house. The firm does sub-contract some manufacturing, such as pistons and con-rods. This is due to the loading on their in-house facilities.

5.6.3 Market and Industry Issues

The company have two markets - domestic and export. The domestic market is dominated by British Rail. The export market is mainly Australia, Africa, South Africa and various developing countries. There is a trend within the railway industry to reducing the weight of railway vehicles. These weight reduction demands can even be made when a system was just being delivered. Penalty payments were also now being demanded by customers for over-weight systems. With the domestic market, due to the size of British Rail Engineering, the firm face two competing demands. One from the engineering department for a technically perfect design. This naturally lengthens the lead-time on a contract. The other demand is from the commercial department who want it now. Delivery is thus the biggest competitive priority for the firm. It takes 12 to 18 months to produce a contract from being given the go-ahead. There are also six to 12 months before this, negotiating the contract.

5.6.4 Design Work

Design work is concerned with two types. Design work for braking system contracts and smaller jobs. Recent brake contracts have occupied nearly all the drawing office capacity for nine to 12 months. There are also ten or 12 other jobs which go through as well. These are mass products which have a simple design and, therefore, occupy very little design effort in themselves. New product design was not appropriate to measure the amount of design work undertaken by the company. Each new contract was regarded as a new product. There were items, as with Theta, such as ancillary equipment, for which new designs were occasionally developed.

5.6.5 Design - Production: Organisation Structure

The company has separate drawing office, design office and planning (production engineering) offices. The drawing and design office are located under the assistant technical manager. The planning department is under the assistant works manager. The drawing and design offices are located in the commercial brick building of the company. The planning office is located at the back of this building close to the shop floor. There is no R&D department, design engineers would be assigned to an R&D project if a market need was detected.

5.6.6 Design - Production: Co-ordination

The company were supposed to have project leaders, or managers, assigned to direct projects. The company , however, did not have enough staff to appoint all the project leaders needed. The project leaders would ensure that the design engineers make time to have the necessary meetings with customers and production. As the company has been expanding over the last ten years they are moving towards project teams. This is a long way off yet. Also they do not have the staff to maintain a stable team. People drop in and out of the teams due to other commitments.

The company held design - production review meetings. These were supposed to be held regularly but were not. They would hold one meeting at the beginning of the contract. The next meeting would be held when the majority of the detail drawings had been drawn, and when production were wanting, or being pressured, to manufacture things. If the firm had more manpower, more of these meetings could be held. However, the CAD manager had found that early production approval was unreliable. This was because production would only give a cursory glance to designs, such as some sort of assembly, until details had been produced. Even if details were shown to production, unless it was ready for manufacture, they would not give it full consideration. This was because they were concerned with current production problems. Thus they did not have the time to consider things until absolutely necessary. This experience with early production approval was underscored by Theta Railway Brake. The implications of this for companies are thus considerable.

As well as the formal co-ordination at the project leader level, informal co-ordination between drafters and planners occurred. This might vary from obtaining production approval for a design to just brain picking. These consultations were supposed to be written up as design review meetings but never were. The company were asked which factors hindered design - production co-ordination. The reply was that departmental barriers, physical separation and differing expectations were not a problem as the number of staff concerned was small. Bad personal relations never lasted long in a small company as people either leave or come to terms with it. The only factor that was said to aid co-ordination was physical closeness. This would, however, only help if the company had more people and time. An additional factor mentioned was the ability to get information across better and soon enough.

5.6.7 Design Process and Manufacturing Considerations

The earliest production aspects considered during the design process were assembly techniques, standardisation and materials, during the detail design phase. Existing products were considered in the conception stage. The other production aspects were first considered in pre-production. The design aspects, engineering and functional design, were first considered in conception. This conforms to the pattern one would expect from a normal firm. The company, partly for the above mentioned reasons, did not try and pull consideration of production aspects earlier into the design process.

5.6.8 CAD Use

Upsilon Railway Brake have a small stand-alone CAD system. This was purchased seven years ago. Initially they had two screens, but after 18 months two further screens were added. Only one screen is colour. The system is a 3D wire-frame system - which has become a 2D drafting system. The CAD system is used for both design and detail drawing. The original intention was to have a CAD/CAM system but this fell by the wayside. Also a solid modeller was desired in order to use it for conceptual design. In the meantime the production people acquired their own CAM package and a DNC network. The CAD system only has one processor and is thus not powerful enough to produce (animated) exploding views. These take too long and fatally degrade the performance of the other screens. It is intended shortly to purchase a new system. This would have a new CPU and software, with two DEC 5000 workstations. In July 1991 another two workstations will be purchased. Then it is also intended to electronically link up with planning and to network all the firm's PCs and computer systems. The old system would be run in parallel with the new for a couple of years. It would be used for simpler 2D work, modifications to designs and for electrical schematics. The number of screens may also be halved.

The company strongly felt the need for the use of a 3D solid modeller CAD system. This would ease conceptual design and aid reduced effort in 2D detailing. This reduction in drawing effort was because such a system could produce 2D views automatically from the 3D representation. Two further pressures were present. The pressure to reduce weight meant the company needed to carry out stress analysis. At the moment this analysis was contracted out to Salford University. This cost two to six thousand pounds per component. With an in-house finite element analysis capability the company could move towards the finite element modelling, and thus design, of components. The second pressure was to pass on more information onto the customers. Again customers required accurate weight estimates, usually very early - during quotation. Producing these estimates manually meant they were 10 to 15% inaccurate. Also customers were passing the production of technical documentation down the line to the firm. These publications, such as maintenance manuals, require the production of exploded views of assemblies and components. This is something which the firm is not yet adequately equipped to produce.

The firm has six drawing boards which are used on and off for drawing. Of these four or five are generally manned. Only six drafters can use the CAD system. They did have eight but two left. The CAD users tend to monopolise the system - with the quicker users staying on as drawings are needed quickly. Initially, with the two work stations, four users were trained by the vendor. With the further two workstations four others were trained in-house. In hindsight this was a mistake, when users are trained in-house two factors degrade the quality of the training. First, they are interrupted. Second, they are asked to produce real drawings. They thus spend time thinking about the design rather than concentrating on learning how to use the CAD.

The firm do not have a library of standard designs on the CAD system. The only standard components held on the CAD system were non-specific ones such as springs and seals. Due to the non-standard nature of the designs the firm produced at best only 10 to 15% of all components could be held in a CAD standards library. These would be the commonly used items. The lack of standards on the CAD system was partly the firm's fault. They wanted to build up a library of standard parts on the new CAD system - there would be no point doing this on the old system. Drawings were filed in drawing number sequence, with no description index. You thus needed a brain to find a design - it is findable but you need the starting point. The firm's MRP system can be interrogated to find where things are used, but it does not give the drawing number. The new CAD system has a bills of material capability and thus can track use from parent down (but not up). The firm have drawn things twice - it is quicker to redraw a design than to find the old one.

The benefits Upsilon Railway Brake had achieved were the same as the majority of CAD users - rapidity of design (most important) and ease of modification. CAD had speeded up drawing, some drawings, however, take as long on a board as on CAD. The company had no policy for directing drawings to the CAD or board. The CAD manager stated that CAD changes your approach to drawing. Anything new was put on CAD, if it was available. Overall assembly drawings were quicker to draw and, therefore, it was worth putting lots on. Some drawings, those which were difficult to draw or dimension, were also put on the CAD system. As far as the competitive ability to reduce lead-times, CAD had not done a great deal. This was partly because the company had not gone CAD/CAM and partly because they do not release drawings early (for the reasons mentioned above). The benefit of simplifying or easing manufacture had only been achieved in relation to the manifolds and castings the firm used. As was the case with Theta Railway Brake, Upsilon instead of connecting valves with piping used an aluminium block (manifold). This was machined on their CNC machine tools. These manifolds had simplified the overall design but were more complex to design. This was because they required calculations to minimise their weight. One big benefit to the firm was the uniform presentation of drawings. Customers require them to provide specific information in certain formats. CAD had enabled them to do this. Asked whether customers gave their CAD drawings to the firm the answer was no. This was due to the incompatibility of CAD systems. All their customers, being large, had CAD systems and were keen to give CAD drawings to the firm. The firm would also like customers' drawings, particularly where it comes to fitting their braking package in the customer's space envelope. That way they could make a judgment as to whether they could just nose outside of the envelope or not.

5.6.9 CAD and Design for Manufacture

Production engineering (planning) did not have access to the CAD system, but an MRP terminal was located in the CAD office. Data had to be transferred manually by typing from CAD to the MRP system. The current MRP system is the second one the company has had. The new system does a lot more. There were quite a few teething problems with its installation. In programming batches of components through the factory the MRP system helps. However, it still needs manual input for this. The system does raise demands - but these are only released when production decide to release them.

The company are not able to use the CAD system for design for assembly. Instead they manually inspected drawings to check for assembly. This was limited to small and simple components. They did not even use the CAD system to move parts in and out to see if they would assemble, as some other firms did.

5.6.10 Computer-aided Manufacture

The company's CAM system was an Anvil 1000. Geometrical information was taken off CAD drawings manually. They intended to use IGES on the new system to transfer drawings electronically to planning. Planning's CAM system does simulate tool path, however, nothing is perfect first time round and modifications must be made in manufacture.

5.6.11 Analytical Issues

Upsilon are a low modification company, 0-10%. Most modifications to designs that were carried out were due to customers' demands: design changes and delivery time pressure. Most of these modifications were due to interfacing problems with other equipment. A few were due to space allocation problems. A few dozen modifications were made in manufacture. These were due to manufacturing problems and due to the large product range. When introducing a new braking system modifications can be up to 30%, after this tails off to only a few. The company actually collated data on modifications before they implemented the CAD system. They found that modifications were going down after they adopted CAD. As CAD had speeded drawing time they are able to go through the design loop several times in order, amongst other things, to reduce modifications. As reported above attempts to release drawings early to production engineering were futile. This meant that modifications were inevitable as the necessary consideration was carried out too late.

Upsilon's Standardisation was high, 61-80%. Components and operational equipment tend to be standard. Packaging and operator controls, however, change from one design to another. The problem for the company was the non-standard nature of their product. This meant each braking system was unique, requiring different variations of basic components to be used. These variations could not be standardised. There was no increase in standardisation due to the use of CAD. This was partly the company's own fault in not building up a large standards library on the CAD system and due to the non-standard nature of their product.

5.7 CAD Cases: Discussion & Analysis

Having presented the descriptive results of the CAD structured interviews this section presents the findings. This is done in two parts - first, the comparative analysis of modification and standardisation is presented and second, the analysis of the other significant issues which emerged from the structured interviews.

5.8 Analytical Issues

Here the findings of the analysis of the analytical issues - modification and standardisation - used to structure the methodology of the CAD structured interviews will be discussed. Firstly, the comparison of the matched pair of firms is presented, in order that the findings and conclusions that emerged from the rigour of the methodology can be seen. Second, a cross comparative analysis of these two issues across all the CAD structured interviews is presented. This latter allows comparisons across type of product, product range and size to be made. Cross comparison goes some way to overcome the inadequacy of the matches, as firms differing on product but equal in size can be compared.

An important outcome of the survey was the finding that CAD had increased the amount of modification carried out to designs after they had been transferred to production. This, when taken together with 30% of firms using CAD in the production stage of product design and the ease of modification benefit demonstrates that firms are changing designs while they are in production. Two propositions follow from this. First, that these modifications during production have a detrimental effect upon the efficiency of manufacture of products, costs, and lead and delivery times. If this is so, CAD far from enhancing a firm's competitive position (presumably the reason for the investment in CAD) can actually harm it. This outcome would be contrary to the expectation of the literature (Arnold & Senker 1982, Blackburn et.al 1985, Campbell & Warner 1988, Ingham 1989). Or, second, the ease of modification provided by CAD enabled firms to a) improve the product during its manufacture and b) to take account of changing customer needs. This responsiveness to customers would improve the firm's competitive position. This latter proposition would imply that the balance between cost and benefits of design modifications during production has been changed by CAD. The survey did not indicate which of these two propositions was the case. The next section below presents the results of the analysis of the structured interviews on modification.

5.9 Modification - Comparative Analysis

The comparative analysis of modifications is discussed in pairs below. First the comparison of the best match CAD firms, Alpha and Beta Conveyors. Alpha Conveyors were low (0-10%) on modification. The reasons for this were the standard nature of their product. Each conveyor system was made up of standard components. The process of manufacturing these was well understood. The modifications that did arise, arose either from production changes or from customer initiated changes. The customer initiated changes were by far the largest cause of the modifications made during production. Modifications for Beta Conveyors were high, 21-30%. Again, modifications were due to two sources either customer initiated changes to the design or modifications necessary to manufacture the system. The modifications that were made were due to the non-standard nature of the product and the particular problems that each design posed during manufacture.

Delta Machine Tools had a low amount of modification, 0-10%. At the prototype stage the company expected a reasonable amount of change: if it does not fit, not easy to assemble or can be done better, it was changed. When a design is in production changes are rolled up to every six months for implementation. These modifications are either new features or maintenance changes. The company used a design review vetting procedure to vet designs for their manufacturability. Also, the prototype stage was used to ensure the effective manufacture of the design. Thus, design changes and changes to fixtures were all attempted to be done before the machine went into real production. Delta were moving toward larger production runs of machines. For example, of the new small vertical machine ten a week were produced. This meant a greater restriction of change as a hiccough would cost more than the saving (of the effect of the change).

A major difficulty for Theta Railway Brake was the fact that products were not developed prior to manufacture. This was due to there being no time or money to spend on development. This, of course, led to problems in production, assembly and testing. In combination with the non-standard nature of the product it obviously led to a great deal of design modification during manufacture, (51-70%). Some of these modifications were due to customers' demands. A major source was the need to meet delivery times. This forced the company to manufacture earlier than should be the case, ie. before the necessary development work had been carried out. The company did admit, however, that they themselves took a little too long in getting designs into production. All of these factors, lack of development, non-standard products and the need to meet delivery dates led to the high degree of modification during production.

Upsilon Railway Brake were low on modification. Most of these modifications were customer initiated. They were either design changes or caused by the customer wanting early delivery. The modifications were necessitated by interfacing problems with other equipment on the train. The manufacturing modifications were largely due to the large product range, with some being down to production difficulties. These would tail-off after a product was first manufactured. It was said that CAD had reduced modifications because it had speeded up drawing and thus increased the number of passes the firm could make through the design loop. Upsilon performed better than Theta for the following reasons. Upsilon were smaller, therefore, they found it easier to control the design process. They produced only current orders and did not produce a history of spare parts - hence the lower complexity of their product range helped. Upsilon were more successful than Theta at managing the delivery pressures customers put on them, their tighter management control also helped.

5.10 Modification - Cross Comparative Analysis

On the modifications issue the structured interviews revealed that CAD was not the determining factor in having high or low modification. The reasons were two fold - the degree of standardness of the product and management factors. On the degree of standardness of product the two close match firms Alpha and Beta Conveyors differed. Beta had a non-standard product which led to higher modifications during production. These were due to customer changes and difficulties of manufacture. Management factors explain the differences between Delta Machine Tools and Theta Railway Brake. Although, Theta also had a non-standard product which contributed to its high modification, Delta had management procedures which enabled them to improve their performance. Firstly, Delta put effort into the development of a manufacturable prototype. The design and fixtures were frozen after the prototype had been developed. In order to iron out the production difficulties a design review vetting procedure was used during the product design process. This involved design and production engineers, manufacturing (make and assembly), purchasing, service, shopfloor supervision, marketing and finance (for machine cost). These people would meet regularly through the design process to ensure the soundness of the design and particularly its producibility. Once in production, design changes due to new features or maintenance changes, were rolled up every six months. Also the firm was moving towards larger production runs. All these factors determined that Delta had lower modification than Theta. On the other hand, Theta did not have the time or money to develop prototypes before starting manufacture. This led to problems in assembly and testing of the product. This lack of resources was compounded by the pressure of the need to meet delivery times for its products. This pressure forced Theta to start manufacture of the product before development had been completed. Hence, the quality of the management of the design process, the degree of standardness of the product and competitive delivery pressures determined the amount of modification carried out during a design's production. The latter pressure can be alleviated by better management control of the design process. It can be concluded from the CAD structured interviews that improving the management of the design process would reduce the amount of modification and thus enhance a firm's product quality and financial and competitive performance.

5.11 Modification Comparison - Conclusion

The CAD structured interviews showed that the quality of the management of the design process, the degree of standardness of the product and competitive delivery pressures determined the amount of modification carried out during a design's production. Management of the design process was found to be the variable which most determined firms' performance. Key management factors were a design review that vetted the design to determine its manufacturability; producing a sound prototype after which no further changes were made and rolling-up production changes every six months. It can also be concluded that CAD had changed the balance between costs and benefits of design modifications - firms were more effectively able to modify designs when the possessed CAD. They could thus correct manufacturing problems and respond to changing customer needs more efficiently - saving time and money.

In conclusion the competitive use of CAD means that management must focus on the whole design process rather than the narrow role of drawing that CAD performs. This necessitates the inclusion of production personnel into the design process and the implementation of management procedures, and mechanisms, such as design reviews. It is these latter management factors that will determine firm's competitive ability. Of course, CAD has gains in speeding and easing the drawing process, but these are prerequisites for competitive strength and not its determinants. This concludes the analysis of modification, the next section discusses the analysis of standardisation.

5.12 Standardisation Comparative Analysis

The second issue investigated by the structured interviews was standardisation. The discussion follows the same format as the modification analysis. As to whether the greater standardisation of components had enabled companies to easily adopt CAD the response was negative. The primary motive for Alpha Conveyor's CAD adoption was the benefits it provided, rather than the highly standard nature of the product. CAD also had not, as yet, led to a greater standardisation of the product. Beta Conveyors did not have standards. The reasons for this can be deduced to be the small size of the firm and the non-standard nature of the product. Each conveyor system was unique and required individual design. Component standards were also difficult to implement, as for example electric motors which had to have different power ratings depending upon the weight of the conveyed material. Thus, the scope for standardisation was low.

Delta Machine Tools said that they were always very good on standardisation but that CAD was a big assistance. The company had a high degree of standardisation, 81-100%. This had helped the company reduce the up-front, or design, time of new machines. The high degree of standardisation in the company was not the reason for the adoption of CAD. They stated that "CAD was of more use to highly standardised firms and, therefore, to us." Theta Railway Brake had a comprehensive standardisation system in operation. BS 5750 approval was achieved very easily due to the standards, procedures and reviews the company already had in place. The company had standards for components such as screws, compressors, motors, pipes, joints. Also manufacturing standards for assembly, and wiring etc. were used. Some of this effort was necessitated by the safety considerations of the railway braking systems the firm manufactured, as well as being indicative of good practice. The non-standard nature of the product meant that product level design standards were not possible. Even some components were not possible to standardise. Upsilon Railway Brake had the same amount of standardisation as Theta, this was because the variety of their products and components was smaller than Theta's but they were subject to the same changing customer tastes. This meant Upsilon could have standards for components and operational equipment but not for system enclosures or operator controls, each of which varied for each customer and were subject to change. Upsilon, however, were also under the same statutory and safety requirements. The next section considers the cross comparative analysis of standardisation.

5.13 Standardisation - Cross Comparative Analysis

Delta Machine Tools had the highest level of standardisation, 81 - 100%, this was because the company invested a lot of design effort in sub-contracting out manufacture - it thus had to develop standards in order to minimise the cost of this sub-contract work. The company also claimed to be good anyway at standardisation, CAD had only helped to reduce the design time and not increase standardisation. All the other structured interviews firms had the same, 61 - 80%, lower level of standardisation. Alpha conveyors did not have a motive for increasing the amount of standardisation, the changing needs of customers could not be met by such an increase. Beta conveyors were prevented from increasing standardisation due to the individuality of each of the systems they supplied, thus their product was non-standard. Theta and Upsilon are interesting, it would be possible for Upsilon to increase the amount of standardisation as they had a smaller product and component range. Theta, on the other hand, would have to change their marketing and business strategy to increase the amount of standardisation. Theta would have to stop manufacturing the wide range of systems and stop manufacturing spare parts and components for old designs and rationalise its components. Such a shift would entail meeting only new orders and refusing contracts for maintenance, modification and upgrading of old designs in service. Whether the firm could afford to do this is doubtful as it would lose market share and upset old (who are also new) customers. The presence of consultants in Theta may mean that some rationalisation will ensue.

5.14 Standardisation Comparison - Conclusion

On standardisation CAD had not led to an increase of the amount of standardisation of products. Rather, the degree of existing standardisation and management implementation of standards determined the amount. These two were influenced by the nature of the firms' products. The more amenable the product was to standardisation the more standards the firm would have standards. Some products due to the market the firm met were non-standard and to increase standardisation would mean losing business and possibly customers. Hence the increase in standardisation could only be achieved against a loss of business - a decision each individual firm would have to make given its own market and business position. This concludes the analysis of standardisation, the next section presents the analysis of the other significant issues.

5.15 Other Significant Issues

The previous two sections detailed the analysis of the two analytical issues used to structure the CAD structured interviews. This section presents the analysis of the other issues which emerged as significant while the structured interviews were being conducted. One of the other issues which the cases studies clarified was the question of measuring the amount of design work a company does by the number of new products it introduces. Alpha Conveyors's design work is oriented to the tailoring of standard components to produce a new system. They do not introduce new products as such. The only new products they introduce are ancillary pieces of equipment (about two a year) - as do Beta Conveyors. Both firms, however, are engaged in a high level of design activity which is not reflected by "counting" these two new product introduction as a measure of design activity. Delta Machine Tools also showed the inadequacy of using new product introductions as a measure of design intensity. They introduce a new product line about once a year - each new line or range of machines, however, must be filled out with intermediate variant machines. It is these latter which determine the amount of design work and not the introduction of a new product. In the case of Theta and Upsilon Railway Brake again new products were insufficient. Both these companies introduced one or two new braking systems per year, but carried out an enormous amount of design work customising the components and sub-systems for the customers requirements. Also, much of the design work carried out in companies was directed towards the current production needs and not towards the introduction of new products. In fact the latter, development work, was sometimes put on the back burner until time was available to carry it out.

Something else which was not possible to inquire into on the survey questionnaire was drawing policy - what determined which drawings were done on the CAD system. Alpha Conveyors put only layout drawings on CAD the rest were done manually. Beta would put all drawing types on CAD. They found that simple components were quicker to draw, whereas, complex ones took as long, or longer, than on a drawing board. Delta determined which drawing to put on CAD by the workload on the system itself - only if CAD was free would a drawing be put on. Theta Railway Brakes found that inexperienced CAD operators spent most of the CAD time on detail drawing as they were not very good at positioning design on CAD. Delta would put similar drawings on CAD, new designs with many years use, designs with a high machining content (as they had a CAM link). Complexity was not a factor in deciding which designs to put on CAD. Again CAD availability would determine its use. Welding, fabrication and assembly drawings were all done manually. Conceptual design and pipework layouts were easier on paper. Of course modifications to previously hand-drawn drawings would be done by hand. Upsilon had found that assembly drawings were quick and therefore worth putting lots on. Again if CAD was available anything new would be put on. Also difficult drawings, to draw or dimension, were put on. Alef Pumps one of the design cases, see later, also had CAD. They had found that CAD speeded up drawing if general arrangement and assembly drawings were put on, particularly the latter as they could be automatically produced by the system. Also availability of CAD was a factor preventing them from achieving greater benefit from it (shortening of lead-times). Hence it can be seen that a major factor in determining whether drawings would be put on CAD was simply the availability of the CAD system.

The research sought to investigate if CAD had improved the integration between design and production through an automation of the design process. Thus, the question as to whether CAD had helped in the early consideration of production aspects during conception and detailed design was pursued. It was found that CAD had not greatly helped in either moving production considerations earlier in to the design process or in aiding design for manufacture. The survey had found that 30% of CAD users were using the system for "Design for Assembly". It was not clear what firms meant by this - due to the ambiguity of the question asked. The structured interviews revealed that any design for assembly that firms are using the CAD for is manual inspection of designs to check that they can be assembled. Sometimes this would just be simple visual inspection of the CAD screen or in some cases components would be moved to around to see if they fitted together. CAD's speeding up of the design process aided firms in their manual inspection of drawings. The second level of CAD integration - conceptual design was only used by three firms. The two railway brake firms used finite element analysis to reduce the weight of components. The third firm, actually a design structured interview Jeem Agricultural Machinery - see the next set of structured interviews - used CAD for the kinematic analysis of mechanisms. This was the most advanced form of CAD use found by the structured interviews, which remember have been chosen randomly from the survey firms.

5.16 Summary

This section presented the results of the analysis of the analytical issues of modification and standardisation for the CAD structured interview firms. It also presented the results of the analysis of the other significant issues (new products as a measure of design intensity, drawing policy and CAD and design for manufacture) which emerged from the structured interviews. The rigorous and novel methodology developed for the structured interviews enabled the results of the comparative analysis to be stated with confidence and the critical factors determining performance to be identified. In the case of both analytical issues it was found that CAD itself was not the critical factor, rather management and management capability determined firms' performance. CAD did have a role in speeding up the design process which allowed firms a leeway in either scrapping designs and repeating the design loop or in modifying designs. This enabled them to improve designs without incurring a time penalty, it did not result in shortened lead-times. It was concluded that CAD was the prerequisite for competitive performance and not its determinant.

It was found that number of new product introductions was an inadequate measure of design intensity, other measures will have to be developed in future research. It was also found that drawing policy - which drawings to put on the CAD system was determined by the availability of CAD. Thus, firms would gain if more access to CAD was available. The more advanced uses of CAD were extremely weak. Only two structured interview firms used CAD for finite element analysis and only one used kinematic analysis of mechanisms. Any design for assembly was not carried out automatically by the CAD system but was carried out by manual inspection of the CAD screen. This concludes the discussion of the computer-aided structured interviews, the next section presents the design structured interviews.

CHAPTER 6

Design Structured Interviews

6.1 Introduction

This chapter reports on the results of the structured interviews undertaken to illuminate significant issues in the management of product design. The structured interviews would complement the survey results. The structured interviews would provide depth to the survey's generality. It was intended that they should also clarify issues which were determined to be significant. The two measures of product design effectiveness, modifications and standardisation were used to help select design structured interview firms. The issues which the design structured interviews set out to investigate were 1) the design production organisation structure; 2) design - production co-ordination mechanisms; and 3) the consideration given to production aspects during the design process.

The process of selecting structured interview firms produced the three products of pumps (a simple product), agricultural machinery and air conditioning equipment (both complex products). This would also allow the comparison of simple products with more complex ones. Fortunately, reasonable size matches were possible.

The names for the structured interview firms have been chosen from the names of the Persian alphabet - in contradistinction to the Greek alphabet for the CAD firms. The pronunciation of the names is as in English: Alef, Beh, Jeem, Sheen, Meem and Noon. The following sections present the write-ups of the six design structured interviews. Each structured interview follows the same format: company background, manufacturing facilities, market and industry issues, design work, design - production: organisation structure, co-ordination, design process and manufacturing considerations, and analytical issues - modification and standardisation. Where appropriate CAD, CAD/CAM and CAD design for manufacture are also discussed. It was felt that this material would be useful both in itself and also to aid the comparison of CAD usage discussed in the CAD structured interviews.

6.2 Alef Pumps - Design Structured Interview

6.2.1 Background

Alef Pumps are a small company, with 100 employees and a turnover of £5.5 million pounds, manufacturing almost the whole range of available pumps. They have been making pumps for the last hundred years or so. They are owned by a German pump manufacturer, but only a small part of their turnover is accounted for by German made pumps. They occupy 1950s buildings. Behind the brick office building is located the factory shed. Pumps are produced on a one-off basis.

The pumps the company manufactures in-house account for 40% of turnover and cover the following range of available pump types: centrifugal, slide channel, liquid ring and rotary diaphragm. The pumps factored from outside are helical rotor and gear combination pumps. Reciprocating pumps have very low sales and represent potential sales in special application areas only. The company market themselves as solving fluid (liquid and gas) handling problems rather than simply as pump manufacturers.

6.2.2 Manufacturing Facilities

The factory shed is some 250m by 75m in size. In-house manufacturing accounts for somewhat more than 40% of turnover. The factory is subdivided into inward stores, machining and assembly and test. The company have three CNC machining centres, with two palette workpiece loaders, and three NC machines. They also have some centre lathes equipped with electronic size controls. The majority of their machines are conventional. The company mainly perform final machining and assembly, with some manufacture of simpler parts, such as sealing rings. The firm buy-in the majority of their pumps. These pumps would have some manufacturing process applied to them, ranging from assembly through replacement of certain parts (particularly seals) to simply repainting and badging. The company's manufacturing strategy places an emphasis on keeping 12 to 15 sub-contractors bubbling with out-work. Each firm would be given at least one job per week, even if it was just machining a seal. Most of the sub-contracted manufacture was v-channel and sheet metal work. This was given to firms with CNC folding machines.

6.2.3 Market and Industry Issues

There has been little change in the technology of the pumps industry since the last century. Pump efficiencies have not been improved. The changes since the 1930s have been in materials, seals and controls. A major innovation of the 1950s was the peristaltic or diaphragm pump (eg. the Kidney and heart blood pumps - seen on films of hospitals). Modern "pumps" can be quite sophisticated and necessitate the use of microprocessor controls. An example, of such a sophisticated application is the car radiator filler "pump" on the Ford car assembly line. This pump operates on a cycle: first the radiator is filled with a water sealant mix, this is then put under pressure - to detect leaks. Then the radiator is evacuated and a vacuum applied - to detect leaks in the other direction. The radiator is then again filled with a water anti-freeze mix and repressurised. This is then released and the "pump" disengages and swings to the side via is overhead gantry. This "pump" is microprocessor controlled to produce the sequence of operations, the mixing, the pressurisation and the vacuum.

The pump industry has been in decline for a long period of time, more than 20 years. Worldwide there is a huge overcapacity in the industry. This creates problems for firms in the industry. Competition, hangs not on price (it costs everyone the same to make a pump) but on delivery time. Alef achieve on-time delivery for 80% of contracts. 15% are a week late, 3% early and 2% later than one week. These latter can take several months to complete. They all involve some form of engineering problem - with the seals or problems to do with the nature of the fluid being carried. The manufacturing strategy of keeping a large pool of sub-contractors bubbling had two benefits. First, if there was a decline in the firm's business it does not affect the shopfloor. Second, the sub-contractors also do not suffer, or go under, as Alef's business is only a fraction of theirs. The only new market the firm has identified was the new privatised water companies. These companies were required not to put raw sewage into rivers. They would thus have to send it to treatment plants. Alef were hoping to gain a lead in this market by supplying an innovative reciprocating pump design, designed by an individual German designer.

6.2.4 Design Work

There is very little design work within the company as such. It is mainly development. This is because the firm do mostly one-offs and, as mentioned above, pumps are a well understood technology. It was thus unnecessary to draw up a written specification. The firm were not actually designing pumps as such. Only the main parameters were needed to produce the pump. As to the introduction of new products very few real new products were introduced. Each one-off contract may include some design variation, particularly in the packaging and mountings. The recently introduced vertical belt drive pump, for example, was packaged in a frame. These frames could have the eye-bolts removed in order that they could be stacked one on top of the other. This would further increase the floor space saving which was the reason for using this type of pump. Also Alef had included a new fibre glass belt drive cover, the design and manufacture of which was separately sub-contracted out.

6.2.5 Design - Production: Organisation Structure

The company had a single engineering department with seven people in it, headed up by the engineering manager. Two of these people were jointly responsible for design, development and R&D. With two others these people made up the engineering section. The production engineering section consisted of three people. Production engineering were responsible for machine tools, best methods and the sub-contract work. Two engineers specialised in production control. This structure was described on the questionnaire as an integrated product-process design department.

6.2.6 Design - Production: Co-ordination

Meetings were most important design - production co-ordination mechanism. The company held monthly project policy meetings. They would set up a project for every significant change. Significant being loosely defined as costing money, a manufacturing project, value analysis or a new product. Every meeting considered each project. The engineering manager chaired the project policy meeting. He was thus in charge of all projects and would activate people etc. to fulfil requirements. If a project were big enough then a project team would be set up. The company sometimes used apprentices as project managers. This was both to ensure their training covered the engineering aspects of their work but also the management: interpersonal and time. The firm would not start a project without a justification. They did not use techniques like discounted cash flow but simply the saving in the first year of operation. If the project had a one year payback period it was adopted. Two year payback projects would also be ok. Three years were difficult and four years were not taken up. The company had, however, justified the changeover from manual to CNC machining on the basis of a three year payback period. The firm were cash rich and they thus go for short term improvements. Any long term improvements due to a new innovative pump design they left to the German parent and its R&D department.

Within each department or section in the firm the managers/ supervisors would regular briefing meetings. These would be on a daily to weekly basis depending upon the manager concerned. These briefings are concerned with up/down communication. Horizontal communication occurred through the Engineering Modification Request Note. These form would be filled in by shopfloor personnel and passed, via quality assurance, to engineering. Engineering would make a decision which had to be passed back to the shopfloor originator. This would either say it had been done, or if not, why it had not. This was very effective and would sometimes locate silly things, such as two identical sheet plates differing by only a tapped hole having different part numbers. Once this was spotted the plates were machined identically and split up for the single tapping. This saved the firm scheduling the two plates separately as different parts through the factory.

Asked about hindrances to design - production co-ordination it was said that departmental barriers were set up by people. Hence, personal relations were the most important factor in co-ordination. It was important to have team building. The engineering manager got on well with most people, although there are always the few odd-ball characters.

6.2.7 Design Process and Manufacturing Considerations

The firm first considered all production aspects in the detailed design phase of the design process. Only existing products were considered in the conception stage. This situation was partly determined by the unchanging nature of the product and the fact that a good deal of manufacture is contracted out. This meant that, for practical purposes, the firm had infinite manufacturing capacity. All aspects were continually considered right into production. This was because the firm was small and there was good co-ordination.

6.2.8 CAD Use

Alef Pumps only used CAD for 2D drawing. The benefits they had achieved were the major ones of rapidity of design and ease of modification. The firm had also shortened lead-times through CAD use. Unfortunately due to time pressure this was no followed up in the interview.

6.2.9 Analytical Issues

For all of the components and pumps that the firm manufactured, or factored, if there was a standard they used it. They not only used British standards but also the German DIN and International ISO. This international standardisation had got to the point where customers need only refer to a relevant standard not just to specify the performance characteristics of a pump but also its design. Thus, the manufacturer's design had been reduced to almost nil. All Of the 32,000 parts the firm had were described as standard. Non-standard parts were modified standard parts.

As mentioned earlier lead-time was the main competitive priority for the firm. The most recent innovation for the firm was the rotary diaphragm pump. This pump was developed to pump highly viscous fluids which deformed and fragmented loosing their properties when a normal pump was used. The rotary diaphragm pump was two and a half years in development. Eighteen months of this was endurance testing. In this testing eight pumps were run continuously, each one differing by one part, to determine the effect on diaphragm life. Due to the special nature of the fluid to be pumped customers for this pump were only too glad when the firm said they would develop one for them. They thus stood the lengthy development time. Most customers, however, require more standard pumping applications and would easily go to a competitor if delays were excessive. Only in the case of engineering problems would they be prepared to wait.

6.3 Beh Pumps - Design Structured Interview

6.3.1 Background

Beh Pumps are a small company, 116 employees and turnover of £6.1 million pounds, manufacturing centrifugal pumps. The company is part of a large diverse engineering group. In distinction to Alef Pumps they do not manufacture reciprocating, gear or diaphragm pumps. They manufacture across the range of centrifugal pumps with heads in the range 0 to 300m, outlet diameters from half an inch to twelve inches and flows less than a litre a second to 1,650 metres per hour. The company manufactures standard ranges of pumps which are modified to meet customer requirements. One-offs are also catered for as they can be very profitable. The only problem with them is that they do not produce growth - that comes from numbers.

The company is located in a rural area. The company's office is a new brick building which was built after the destructive factory fire in 1974. After this fire several of the firm's buildings were resited and rebuilt.

6.3.2 Manufacturing Facilities

The company's factory is located in several sheds - a principal one and two subsidiary sheds plus miscellaneous stores. The principal shed contains most of the factory. This consisted of raw material stores, machine shop, assembly and test. One subsidiary shed contained the machine shop for the solids pumps. A second contained the paint shop. One shed acted as a component store. The company had two sets of CNC machine tools. A British TI-Matrix set of a vertical and horizontal machining centre located in the subsidiary shed. A Japanese Hitachi set which was acquired from a firm that was taken over by the firm. The firm buy in prime movers, such as diesel, engines. All pump parts are manufactured in-house.

6.3.3 Market and Industry Issues

The companies markets are the water supply, construction and mining, the UK and US plant hire, heating and ventilation, paint and process industries. The company is the market leader for pumps in the construction and mining industry. Two years ago (1989) the company stopped the production of piston pumps as these are associated with cheap competition from the third world. In the last 18 months (since beginning 1990) the firm has worked on industrial pumps. The firm also inter-trades with other pump companies. The pump industry is moving towards increasing standardisation of pumps for which the firm is developing a range of ISO standard pumps. The company's policy is to get into new markets through entry or acquisition. Up to four new markets had been entered per annum over the last two years, including acquisitions brings the number to 20.

Forty per cent of the company's output is exported to North America, Europe, Africa and the Middle East. Competition centres on price, delivery and quality. The firm does, however, sell on quality alone. In the recession delivery has become more important.

6.3.4 Design Work

The redesign of the company's standard range of pumps usually takes the form of the redesign of the mechanical seals and the use of different materials. The hydraulic parts of the pumps do not change. The entry into new markets and the acquisitions has meant a great deal of design work for the company. This has involved a certain amount of reinventing the wheel (of centrifugal pumps) in stream lining the range of pumps offered. Thus, hydraulic designs have been modified followed by mechanical ones. The development cycle for a new pump was from 15 to 18 months. The firm introduced three or four new pumps a year.

The design process for new products depends upon market. In construction and mining distributors are heavily involved in the process, whereas on other lines the company's own sales and marketing department is involved. The technical director writes the product specification and extensively consults with the sales and distributors as outlined above. The development process would be a step by step one, involving four to five people from sales and engineering. A single product would be developed at a time rather than a range of products as this method led to less technical failures.

Most of the design work in the company relates to production - as this is the immediate demand. The drawing office thus spend most of their time on immediate production requirements. Project work (new products etc.) is carried out in combination with the development department.

6.3.5 Design - Production: Organisation Structure

The structure of design and production is split between the technical director and the managing director. The technical director heads up the integrated engineering, service and production engineering departments. The managing director also has responsibility for production engineering and the works manager reports to him. The engineering department consists of three CAD engineers, two drafters, a technical engineer, two development engineers and two development craftsmen. The production engineering department has one production engineer and two quality assurance engineers.

6.3.6 Design - Production: Co-ordination

Meetings were the most important co-ordination mechanism used by Beh Pumps. Informal consultation was the next most important, these being the only two mechanisms used. Regular development meetings were held approximately every two months. These would involve the drawing office and production engineering. Extensive informal co-ordination was central to the firm's whole approach to design. Only for certain types of pumps was there a formalised development programme. Three years ago there was no production engineering input into the design process (until the production stage was reached). The technical director had introduced a production engineer into the drawing office to bring in production considerations while the design was being drawn. The person appointed was an ex-apprentice of the company who had rejoined. He was able to interchange between the shopfloor and the drawing office very effectively. This interchange peaked at build time when he was continually liaising with the fitting shops. The factors which hindered co-ordination most were departmental barriers and the existing production commitment and load. In order to improve co-ordination it was necessary to develop common expectations between design and production.

6.3.7 Design Process and Manufacturing Considerations

Of the production considerations only standardisation, production processes and materials were considered during the detailed design phase. All other production aspects, bar assembly, were first considered in pre-production. Assembly was considered during the prototype stage. It was said that pumps are very standard items and consideration of production can be left until a late date.

6.3.8 CAD Use

The company had recently (a year ago) installed a CAD system. This is a small system from a medium sized computer manufacturer. Three workstations were installed initially with a final fourth one soon to be installed. The system has a sophisticated Design for Assembly module which allows assembly drawings to be produced and checked automatically from component drawings. It is also capable of mechanical and kinematic conceptual design but the company have yet to explore this aspect of the system. It is intended to add a 3D module in two to three years time in which case the company will also experiment with conceptual design. When the company first obtained the system they put a mixture of old and new designs on the system. The company were now using the system to produce drawings for straight forward production items. With the new range of ISO pumps it would be possible to withdraw the old products and concentrate on new design only. Drawing productivity had increased, this was particularly due to the ability to produce general arrangement and assembly drawings automatically. This will save the company taking on one drafter in five, thus enabling the firm to meet its policy of containing staff numbers. The other benefits of the system were ease of modification and rapidity of design. The CAD system would shorten introduction lead times if sufficient access to the CAD workstations could be made. This was not possible, however, due to the demand from normal production work. The next stage of the CAD system development was to integrate it into sales. The company also have a separate stand alone computer production control system which is not MRP. CNC programming is not available on the CAD system but is carried out by the operators on the shop floor.

6.3.9 Analytical Issues

Beh pumps were low on modification, 0-10%. Most of the modifications that were made arose from production difficulties. These were said to be general problems rather than being specific to production processes or pumps. One problem area was machine shop tolerances. All design changes would be reviewed in order to determine their impact upon the design and production. Modifications would initially be high when a new product was introduced but after a year or so would fall off. The company had a quality assurance procedure. This consisted of Engineering Change Notices. This was motivated by the need to get British Standards Institute BS5750 approval so that they firm would not lose business.

Standardisation was given as 21-40%, quite low. The company have developed a range of standard materials. They also have standard components and interchangeability of them across pumps. An example was bearing brackets of which there were two standard ones used across twenty two pumps. However, it was said that interchangeability can be a bad thing as some items and materials are crucial and thus cannot be interchanged - eg. the company's use of silicon carbide. The company had now increased there standardisation to 60%. They were also developing a range of ISO standard pumps. This would further increase the amount of standardisation. Customers could then use the ISO standards to specify a pump and the firm supplied them the relevant standard pump.

6.4 Jeem Agricultural Machinery - Design Structured Interview

6.4.1 Background

Jeem Agricultural Machinery are a medium sized company, of 220 employees and £14 million pounds turnover, producing hedge cutters, digger loaders, cultivation machines and turf maintenance machines for the farming industry. The company have been on their present site since just after the Second World War. The company's agricultural machines are produced in batches and distributed through dealers. Each machine is thus a standard model with different minor variations. With the hedge cutters, for example, there are eight basic models. The company introduce new models every five to six years. These are either new models with a higher technical specification or they incorporate major design changes. The company manufacture most of their components in house. They buy in castings, some sheet metal work and hydraulic components. Sixty per cent of turnover is accounted for by the hedge cutter range of machines. These, and the company's other products, are designed to fit on the back of tractors. The company also do a little sub-contract fabrication, eg. a large digger bucket for Massey Fergusson.

6.4.2 Manufacturing Facilities

The company's factory consisted of a set of partitioned large "open plan" "sheds". These were divided out into raw material stores, bending and cutting shop, machine and welding shop, paint shop, assembly shop with test area and final stock store with dispatch area. Most of the buildings dated from the early fifties with two new ones being added in 1970. Each batch of 24 machines in production would work its way through the factory from one end to the other. The company possessed two Japanese CNC machining centres, several C/NC lathes and a CNC bending/punching machine. The company also had a robot welder which was used only for simple jobs, eg. tanks. This robot was bought using a government grant and probably did not justify its use otherwise. The company also possessed a CNC plasma metal cutter which produced a lot of scrap, the older flame cutters were better.

6.4.3 Market and Industry Issues

The market the firm meets is that of the farming industry. This industry has suffered in the last five years from a fall-off in profitability. This has affected Jeem's level of business. Three years ago the company introduced the range of turf maintenance machines to counteract this trend. However, only a few of these were sold each year. Further, the company's other core product - loader diggers - had also suffered a loss of demand over the last decade. This was due to the availability of cheap "JCBs". The company's business was seasonal, machines selling in the summer. However, the company operated through dealers and would thus produce all year round. They would get the dealers to order their year's requirements in December. They would then hold the machines in stock until delivery was needed. The company also sold some of its machines through an associated French firm. Primarily, a special machine for the French market was produced. Similar arrangements with stock and delivery were in operation, the ordering period being mid-February. Competition in the industry centres on price. The company, therefore, look to simplifying a design to save costs.

6.4.4 Design Work

Design work within the company is oriented towards the design of variant machines of the basic models and the introduction of new models. Each model range would have a planned life of five to six years. Variants to the basic machine would be introduced only if its specification was radically different to the machines in the current range. These differences could be either an improved technical specification or design/ manufacturing improvements. The marketing and design directors would decide what the market requires, and at what price. The design director would then place a costed specification on the table. One, or two, prototypes would be made. Approval would then be given to start production of the new machine. For a fairly radical machine market tests would also be performed. Also production quantities would not be made until after the market launch. If the machine was a replacement for an existing one then production quantities would be made before the machine was launched. The company had also changed its manufacturing strategy. It used to manufacture machines in batches of 24 identical machines. Recently, it had started producing batches of 24 machines which were not quite identical. They were now moving toward the manufacture of components and sub-assemblies. This had all meant more effort in building up the machine structure (bill of materials).

6.4.5 Design - Production: Organisation Structure

The company had a design department and a development section in the factory. Both of these are headed by the design director. Due to the down turn in business only five designers were employed - half the numbers of ten years ago. The production engineering section is located at the other end of the factory. This comprises CNC programming, methods and jig and tool design sections. These are headed by the works manager who is responsible to the production director. As the company was small rigid hierarchies were not in evidence.

The company also had product committees for each of their product groups. This consisted of representatives from sales, design, production, and buying or accounts. Each of these committees had a wide brief for the product group - looking at marketing trends, production opportunities and costs. The committees were usually chaired by the marketing director.

6.4.6 Design - Production: Co-ordination

There were two main mechanisms for design - production co-ordination within the company - project engineer and milestone meetings. Within the design department a project engineer would be appointed for a machine project. This person, usually one of the firm's two senior engineers, had responsibility for design - production liaison. An informal project team consisting of the project engineer, a junior engineer and a hydraulics engineer would then carry out the actual design work. Three milestone meetings would be held. One at the project definition, or specification, stage - as already alluded to above, this was a heavily marketing led exercise. The second after all the detail drawing had be drawn and the design costed. Finally, after the prototype testing had been completed. It was at this final milestone that production engineering became involved in the project. The meetings of the product committee and the milestones were said to have helped design production co-ordination. The company had not gone for BS 5750 approval. They had the necessary procedures documented but had not implemented all of them.

The reason given on the questionnaire for hindering design - production co-ordination was differing expectations. The design department, as they were close to the customer, but not as close as sales, felt that they had to respond to customer needs. Production, on the other hand, wanted one design that could be mass produced. The firm attempted to reach a compromise by adopting a "box of mechano" approach. Thus, a kit of parts would be designed which could be differently assembled to produce a variant of a basic machine. Thus customers' needs would be balanced with (mass) production requirements. Asked if customers were knocking on the firm's doors requesting changes the reply was "only to some extent". Design would first check to see if a current design could be stretched to meet the customer's need. The firm would only produce a special machine in exceptional circumstances - such as a new technical development. Otherwise, such requests were turned down, unless they mounted up and justified a new specification of machine. The product design cycle would then be invoked and a specification drawn up and the machine costed.

6.4.7 Design Process and Manufacturing Considerations

In terms of during which design stage the company considered production aspects the following situation existed. The company considered some aspects early and the rest late. Thus, standardisation, production processes, assembly techniques and materials were all considered in the detail design stage, that is, early. Plant, machinery and labour requirements were considered fairly late, in pre-production. The reason for this was twofold: The maturity of their business and concomitantly the designers' good knowledge of the firm's manufacturing facilities. During the detail design phase designers would use their knowledge of the production process to produce designs which were manufacturable in the firms factory. The designers would also concentrate on making the design cheap to make - by reducing the amount of material and ensuring ease of assembly. Thus, detail design was seen as the crucial stage. Here, decisions as to how designs would be made and where they would be made (in-house or out) would be taken. This latter decision could always be changed later on for capacity or economy reasons. An example of the designers' knowledgeability was the CNC produced parts. The CNC programmers would expect designers to produce designs which understood the capabilities of the CNC machine tools. The company felt there was not much gain in involving the CNC programmers in the detail design. At best it would simply produce more options - for example to buy-out cast parts rather than machine them in-house. Normally, the firm went with the first satisfactory solution. The firm also took this approach in the product specification - no production engineers were involved in its drawing up. They would only be involved, at that stage, to cost designs - internally and by external sourcing.

6.4.8 CAD Use

The company had purchased a fairly sophisticated Hewlett Packard CAD system in August 1989 (18 months previous to the interview). They had intended to acquire three workstations but due to the down-turn in business only had enough money for one. The design director was skeptical of the gains that could be made with the CAD system before it was purchased, but he had now become enthusiastic about it. It had been good for the company. People in the design office were only too keen to learn to use the system. The company only used the CAD system to produce new designs. They did not have a policy to determine which drawings, or products, were done on CAD. Hence, if an individual designer started to design a new machine on CAD that machine would be totally designed on CAD. Hence, some new machines were designed on CAD and others not. For the machines done on CAD the company was building up a library of standard parts. The company had made some drawing productivity gains, particularly for complex drawings but not for simple ones. The CAD system had helped in making it easier to see if assemblies fitted together. In this the company used a manual design for assembly technique. That is manually moving things around the screen and changing their size so that they fitted together. Also CAD had been useful in producing the flame cutter profile drawings, which previously were tedious to produce.

The company had also commissioned the CAD vendor to write a kinematic analysis program for the company. This was used to optimise the kinematics of the robot arm mechanisms that carried the hedge cutter heads. This had both made the process of mechanism design more foolproof and also increased the sophistication of the mechanisms produced. Previously, the company had used cardboard models and drawing pins to simulate mechanisms. Now the specialist analysis program allowed them, from the mechanical analysis, to calculate forces and thus loads and velocities. It was hoped to purchase a finite element analysis package which would be used to model stresses and thus to reduce the metal content of the mechanical arm. The company had seen this opportunity and were not being induced into it by the competition. It could, therefore, provide a competitive edge for the company given the price sensitivity of the market, as reducing the amount of material meant cost savings. The package had also enabled the company to increase the sophistication of the product. The optimisation of the mechanisms meant that the company could now do things with mechanisms that it previously could not. This optimisation and the rapidity of drawing on CAD had translated into reduced lead times for the company.

Before the arrival of the analysis package the company relied on the prototype stage to iron out problems with the mechanisms. This would even involve checking that the mechanisms did not lock up or go off centre. They were now able to prove the mechanism on the CAD system to eliminate these difficulties before the prototype was built. Plus, of course, they were able to carry out the more sophisticated fine tuning of the mechanisms mentioned above.

6.4.9 Computer-aided Manufacture

CAD can greatly aid the bridging of the design - production interface by being linked to CNC machines. The company had two machining centres, a number of CNC lathes, a CNC bending/ punch machine and a plasma cutting machine. The company has had CNC for the last ten years. Drawings were passed on disk to the CNC programming department. This meant they no longer had to digitise designs from the drawing before writing the CNC program. This had been a benefit to the company.

6.4.10 Analytical Issues

Jeem Agricultural machines were low (0-10%) on modification. The reasons for this were the maturity of the business and the extensive knowledge of the company's manufacturing processes possessed by the designers. Modifications that did arise, arose from reliability problems, suppliers changing component designs, and some customer originated changes. Production problems were usually due to tolerances in assembly. Most modifications were due to suppliers changing the size of their components. Customer originated changes would only be adopted if the market was moving in that direction.

The company had standards for materials, components, dimensions/ tolerances and fasteners. For fasteners a numbering system was in operation. A lot of the company's designs contain pin joints and they had introduced a pin chart to standardise pin sizes. Materials were coded with a part number. The company also had a machine structure, starting from the top (the product) down it listed all the components and their part number. The problem with component standards was that sizes and shapes were always changing - partly due to the need to reduce material. It was difficult to retrieve odd-shaped size plates from previous drawings. The company hoped that the CAD system would make this easier.

6.5 Sheen Agricultural Machinery - Design Structured Interview

6.5.1 Background

Sheen agricultural machinery are a medium sized company, having 180 employees with a £8.5 million pound turnover, producing grass topping, mowing, baling and feeding machines, bedding making machines and muck spreaders for the farming industry - principally livestock farmers. The company has seven ranges of machines, each with a different seasonality. Each machine has a life of six to ten years (if lucky), and would go through two or three marks. To stay competitive the company must bring in at least one new product a year. The company have been located on their present site since before the Second World War. The company used to use dealers but now deal directly with customers (farmers and contractors). Demand is seasonal with machines being produced in batches. Deliveries are met from finished stock and later in the season from machines assembled from component stock. The principal product - grass mowers - has a range of three machines, each of which is a separate design. The company manufacture most components in-house, the exception being sheet metal fabrication which is sub-contracted out to an affiliated company. All the company's machines fit onto the back of tractors, including the harvesting machine which is in development.

6.5.2 Manufacturing Facilities

The company's factory consisted of a large open plan multi-shed which had been extended over the years. It was divided into the following sections: raw material stores (sheet and bar metal), sheet metal shop, small welding unit, machine shop, development and jig and tool section, washing and paint section, assembly and test area. A covered stock yard for finished machines and componented machines was located outside. Batches of machines would filter their way through the factory from the stores end to the stock end. The company mostly had manual machine tools - primarily lathes. They possessed one CNC punch machine of which they were hoping to purchase a second one. The two old bending machines it was also hoped to replace. The company were also hoping to purchase a CAD system but lacked the capital. The company aimed to keep the factory fully loaded as a fall in loading by 10% meant a fall of 1% in their gross margin. If the cost saving of subcontracting was only 5 to 10% then it was kept in-house.

6.5.3 Market and Industry Issues

The market the firm meets is the farming industry. This industry has suffered a fall in real income of 40% over the last five years. The company's products are principally aimed at the livestock farmer. The company understood the livestock market and its needs. They produced a machine for nearly every stage of the lifecycle of livestock: grass to feed and, via the livestock, muck back onto the field. The company's level of business has suffered due to the contraction in the farming industry. This is compounded by overcapacity in the engineering industry. The company has nine competitors. Price is extremely competitive. The strategy the company had adopted to counteract this was to move to a just-in-time manufacture and sell policy. Previously, the company used dealers to hold buffer stocks but now dealers cannot hold much stock. The company now produce final machines, and stock components for later assembly, in batches to a forecast with some build in-season. All machines must be sold by the end of June - the end of the season. At the time of the interview, late May, they had 50 machines in component stock. The grass mowers, for instance, were built in two batches of 80 each. Small components were manufactured in a flow line of batches of 100.

Twenty five per cent of the company's output was for export. Roughly equally divided between Ireland, Europe and North America. Exports have grown from their level of 12-15% three years ago and the company plans to further increase them. This was done by following a niche marketing strategy. Indeed, for the North American market a specific machine was developed.

6.5.4 Design Work

The company introduce at least one new product each year. This would either be an upgrading of an existing machine in a range or a wholly new product. The company had in development a harvester machine. Priority to production needs and new models was given in the design office, thus the harvester was kept on the back burner. Its launch may be put off until 1994 or 1995. The design work was characterised as replacing a dying product which involved updating the whole range of machines. It was said the company was running to standstill. Hence, the reason for the harvester development - to provide organic growth. Last year the range of mowers were updated, this year balers and next year feeders would be updated. The load on the design office would vary from one machine range to another - the muck spreaders range consisted of only two machines. The company did not use contract draughtsmen to overcome the overloading problem. They only used external draughtsmen for specialist areas, such as augurs.

The company, when introducing a new product, started with the market, a one page performance brief was drawn up by the marketing department. This specifies sizes, power ratings, cutting and travel speeds etc. Previously the specification was written by the sales manager and took the form of a technical specification. The managing director changed this such that marketing only produced a performance specification. This performance brief was then passed to engineering who checked to see that the engineering principles of the design would work. A technical outline (not a fully fledged specification) would then be drawn up. It consisted of loadings, horse powers and some sketches. If the engineering principles were proved then in September a project team would be created. After a prototype had been built, five pre-production prototypes would be built by the shopfloor. These were extensively tested by the company on local farms and were also sent to large farmers and contractors where difficult conditions existed. The aim was to have each machine cover 5,000 acres by the end of the season in September. Reliability and serviceability were the main concerns of these tests. Feedback would be obtained from service engineers, production, customers and shopfloor and development fitters. In September/October a melting pot meeting was held between design, factory, marketing and service where the design was frozen. During October to December the jigs and fixtures would be made ready for production in January.

6.5.5 Design - Production: Organisation Structure

The company has an integrated product-process design department. At the moment the two functions are located in different offices, but they will soon be located in the same office. The design function consists of five engineers, including the design manager. Production engineering is staffed by a production engineering manager, two and a half production engineers and three and a half production planners - the two halves are the same person. The combined development department-toolroom has six craftsmen. This department is responsible for both prototype development and also the design and manufacture of jigs and tools.

The company holds regular product review meetings to assess the performance of product ranges. These meetings, usually chaired by the marketing director or, if the meeting involved more than two departments, by the managing director. The meetings included the design manager, and or the appropriate design engineer, and the production director or manager. The reviews consider the market and technical performance of machines in production and the progress of machines currently being designed. Feedback from service, production, customers, and shopfloor and development fitters would be discussed and adjustments to the company's design policy made as appropriate. The meetings would thus consider major decisions and those involving large sums of money, such as the £40 - 100,000 development costs of a new machine. The company's aim was to keep cost and function of designs in balance.

6.5.6 Design - Production: Co-ordination

The principal method for design - production co-ordination was a project team. This would consist of a design engineer, a production engineer, production manager, tool room fitters (who were responsible for developing and building prototypes) and three shopfloor representatives (mostly fitters). During the prototype development stage there was continual informal engineering - shopfloor consultation. Every couple of months design - shopfloor review meetings were held to discuss and resolve manufacturing difficulties.

The philosophy of the company was to keep meetings and participation in them to the minimum. Asked if there were personality clashes, the reply was that for those individuals where a problem did arise it was a case of taking the person to one side and counselling them. The clashes which did arise were discipline specific rather than personal, the objectives of the functions are different which naturally led to problems. Hence, marketing want the best performance, cheapest machine, whereas engineering want the best technical one and production the easiest to make. The greatest gap was between marketing and engineering. The solution was to get the personnel of the different functions to work more together, the more they did the better they got at working together. The managing director, the interviewee, related the experience of the company since he took over two and a half years ago (at the time of the interview). The company was previously led by a brilliant designer and engineer and thus the company was design led. The company had invested a lot of design effort in a 10 foot 3 mowing machine which unfortunately was a commercial failure - it was 50% over cost. This was the trigger that brought the current managing director in from outside. The new managing director had reorganised the design and engineering functions. He also made them work together as previously the production personnel had little input into design. The engineers had realised that the company was too technically oriented, this had helped them all work together. In the early days they were defensive but through working together they were now quite friendly. Any conflict which did occur is now more easily resolved. Over time the engineers have become better at working together, the design engineer is now thinking of production while he is designing. Under the previous regime designers were not allowed on the shopfloor, now a designer oversees the development of new designs on the shopfloor. The managing director wants to carry on this collaboration by locating the design and production engineering personnel in the same office.

6.5.7 Design Process and Manufacturing Considerations

The primary manufacturing concern of the company was assembly. Over time the company had improved - the introduction of the latest machine had considered assembly right from the start. At the pre-production stage production engineering and the shopfloor were fully involved. Standardisation and materials were both considered in the detailed design stage. Production processes and plant were considered in the prototype stage. Only labour and production control considerations were left until pre-production. Production engineering did not have veto over designs, the aim being to achieve good design through consultation. Where problems do arise the managing director arbitrates them deciding what is pragmatic for the company and its market.

6.5.8 Analytical Issues

The company had 11-20% modification, higher than Jeem Agricultural Machinery. At the prototype stage approximately 20% of component would be modified. Roughly half of these arose from customers, there being a slight bias (up to 5%) towards the factory. Every two years customer's modifications would be rolled up. At the design-production review meetings modifications would be discussed. The factory could raise any manufacturing problems. A decision to change a design would follow a set procedure. If there was no impact of the change on machines in the field the change was approved. If there was an impact on machines in the field (ie. a spare part implication) then marketing were brought in to aid the decision. Sometimes, rather than individual parts being changed, changes were incorporated into interchangeable assemblies.

The company had also increased the attention it paid to standardisation. The firm gave its level of standardisation as 21-40%. They had developed a preferred list and reduced part numbers down from 19,000 to 14,500. They had also implemented standards not just within machine ranges but across them, for example with standard size axles. Previously, they had found that they were using four different gear boxes on four different machines with a price variation of 5% between them but each having the same ratio. Buying a standard gear box in bulk (four times for one instead of four by four) meant not only simplifying design and saving costs but also obtaining favourable quantity discounts. The MRP I system had been useful in spotting the multiple use of similar components - bearings being another example. Purchasing also had access to the system to help substitution.

6.6 Meem Air Conditioning - Design Structured Interview

6.6.1 Background

Meem Air Conditioning are a medium sized company, of 330 employees with a turnover of £27 million pounds, producing air conditioning systems for computer rooms, telephone exchanges and offices. These range in size from one to 50 units per room to small units for one or two person offices. Each of the larger units would typically occupy a wall area of one metre square. The company market a quality product and only make to order. All of the company's products (the air conditioning machinery but not the ducting) are sold through distributors. The company is wishing to cut out these "middle-men" and sell direct to customers. The company manufacture several ranges of air conditioning equipment with many options. Each range consists of five or six machines of different duties, there are then five different types of cooling circuits (giving 25 different units) plus airflow and discharge options which bring the total number of possible units to about 100. Each of these permutations would be met from standard units with the relevant options fitted. One-off requests from customers would only be considered if they were lucrative. The company only assemble the air conditioning units, all components, including sheet metal, are bought-in.

In order for the firm to meet an order the customer's specification is first examined by sales to determine which air conditioning units etc. to use. The resulting information is passed to purchasing who draw up a bill of materials which is entered onto the MRP II system. This information is then processed by the technical drawing office to produce route and build sheets and picking lists for the different sections of the factory (electrical, mechanical, coils etc.).

6.6.2 Manufacturing Facilities

The company's manufacturing facility has been located on the present site for fifteen years. The commercial offices were, up until three years ago (since 1988), located at the previous manufacturing plant some miles away. Consolidation of manufacturing on the present site took place five years ago. The company actually consists of three companies, the air conditioning firm, a "compact" (ie. small office sized) air conditioning firm and a sheet metal fabrication firm. All three companies are located on the same site in the large open plan factory shed. The air conditioning operation is dominated by assembly. There are several assembly lines for the different ranges of air conditioners. The assembly starts from the sheet metal cabinets (bought from the sister company) with the internals (compressors, cooling units, controls, fans etc.) being installed as the cabinet moves down the line. Extensive quality checks are carried out on the bought-in components, during manufacture and after final assembly. Each completed unit is tested at the end of the assembly line. Apart from test equipment the company did not possess any machinery.

6.6.3 Market and Industry Issues

Meem's principal markets are the computer and telephone industry, and secondarily the office market. The company faces fierce competition from America, Europe and Japan. Japanese technology is a lot more sophisticated than British and has been eating away at some of the firm's markets. The company wishes to ensure repeat orders from its customers and so has adopted a policy of supplying quality air conditioning systems. This has meant that efforts to continually update products must be made. Secondly, the company must continually search for space in markets that it can fill. This is done informally but market surveys are also commissioned.

6.6.4 Design Work

The company introduce a new product range every two years. The company's design work is split 10 to 20% production oriented, 20 to 30% new products and the rest updating designs and information control (of drawings, standards and modifications etc.).

The process of new product development is illustrated by the in-process development of a new compact air conditioner. The applied products manager of the marketing department researched the market and produced a specification of what is required. Having defined the market and specification for the new compact machine the applied products manager and the engineering manager held a meeting to set a timetable for introduction. A critical path analysis was done and a Gantt chart drawn. This showed that the project would run for 69 weeks. A project team of four members was set up which would be dedicated to the new product.

6.6.5 Design - Production: Organisation Structure

The company had a different philosophy and organisation of engineering for design and engineering for manufacture than other air conditioning manufacturers. Other firms had separate design and engineering functions whereas Meem had a single integrated product and process design department. Other companies operated a philosophy of "throwing the design over the wall to manufacturing" whereas Meem made strenuous efforts to include manufacturing considerations and manufacturing personnel early on in the design of the product. This difference was seen in the organisation of the "engineering" department. This consisted of two senior project engineers, one project engineer, a senior mechanical engineering draughtsmen, two mechanical engineering draughtsmen (one on CAD), a senior electrical engineer/ draughtsmen, an electrical engineer, a standards manager and a test manager. The engineering manager was in charge of this department, and was also the quality manager. There was also an office manager who was responsible for office and project administration. This department formed the integrated product and process design department. The only production engineering personnel in the firm were under the production director. They were only responsible for the drawings of pipework. Likewise, the sister sheet metal company employed its own CNC programmers and production engineers.

6.6.6 Design - Production: Co-ordination

There were three levels of co-ordination in use in Meem Air Conditioning. First product review meetings, formal meetings at milestones, and informal consultation. The project leader of the project team would hold meetings at the milestones of: before and after prototype construction, before and after production machines were produced. The first production meeting may, or may not, be held depending upon the outcome of the second prototype meeting. Six months after product introduction another milestone meeting was held to check that everything was ok. For each project a project review meeting would be held monthly, six weekly or more often as necessary. These meetings would review progress and set deadlines. The company placed an emphasis upon informal design - shopfloor co-ordination in order to ensure ease of manufacture. The philosophy was to engage in as much interaction as possible until things were running smoothly. Thus a project engineer would hold informal consultative meetings with colleagues to approve, and advise upon, designs and would also visit the shopfloor to show drawings in progress and to obtain advice. This interaction with the shopfloor would continue during prototype construction. The company had recently changed its prototype development policy. Previously, prototypes were built in a specialised development department. This department had been disbanded in favour of building prototypes on the shopfloor. Thus the fitters responsible for ultimately building a machine would actually build the prototype. The project engineers would visit and consult with the shopfloor as the prototype was being built. They would then make changes to accommodate ease of build, ease of access, ease of maintenance, ease of component replacement for service etc. The pressure of competition meant that price was very sensitive and this meant that production time had to be minimised - by ensuring components were easy to assemble and the best way to assemble them was used. As the project engineers do not spend all their time on the shopfloor they do not know the best way to make something and thus it was necessary for them to consult with the shopfloor on this issue.

Co-ordination and communication within the company was also ensured by cascade meetings. Monthly production meetings of all departments were held, chaired by the managing director. Disputes would be arbitrated by the managing director. Each department would then hold a concomitant meeting. Then each project team would hold review meetings as necessary. The company also employed the use of Total Quality Management (TQM). TQM had been the catalyst for increasing interdepartmental communication, both formal (paperwork) and informal consultation. There was a philosophy of continual improvement in operation in the company. TQM had thus helped to reduce the barriers between departments. Physical separation had hindered relations between departments in the past but now everyone was in the same office it was not a problem. Personality clashes had to be dealt with professionally - that is to be accepted and the job to be gotten on with. There was no room for clashes to last long, particularly as people with problems tend to leave.

6.6.7 Design Process and Manufacturing Considerations

The company were early to medium in their consideration of production aspects of design. Plant and existing products were considered in the conception stage. Standardisation, machinery and materials were considered during detail design. Assembly techniques and labour requirements were considered during the prototype stage. In discussion this was embellished by indicating that assembly was also considered during detail design (as related above) and that machinery was considered during prototype build. The concern to minimise production time led the company to place an emphasis upon the utilisation of fewer components. This made assembly easier which led to fewer mistakes, both of which reduced assembly time. An example of this was a fan unit which was used 5,000 times. Previously the fan was assembled from components into the cabinet. Now the company bought a fan unit from a different supplier. This fan unit was £8 cheaper and saved ten minutes build time. Thus the savings of using the fan unit over assembling one were great.

6.6.8 CAD Use

The company obtained it CAD system some two and a half years ago. They bought eight workstations which were initially only used for electrical design. CAD use for mechanical engineering only started 18 months ago. This was sporadic and not systematic. One project engineer used CAD for all his mechanical design work as he worked on special projects.

6.6.9 Analytical Issues

Meem Air Conditioning had high modification, 11 - 20%. There was a procedure in operation for changes either production generated or other. Production modifications would be originated by shopfloor personnel filling in a change proposal form. This was sent to the engineering manager for approval. The quality manager (also the engineering manager) had to give approval too. Questions would be asked as to which unit the modification affected and how many. A checklist was used to consider the effect a modification would have. After approval the standards manager would issue drawings to all concerned parties: stocks, purchasing, spares, sales etc. This issue of drawings was controlled in order to ensure that the most up to date information was used. An information bulletin informing distributors and customers was also periodically issued.

Production modifications arose to improve access during assembly, to make a better fit, to include access panels (for access and/ or service). Engineering changes would arise from suppliers changing component sizes and other sources - eg. product improvement. Independent of the source of the change major modifications would be introduced immediately, others would be prioritised and rolled-up for introduction. Strenuous attempts were made during the prototype stage to eliminate modifications in order that they were minimised during the changeover to manufacture.

The company had a high degree of standardisation, 61 - 80%. The company's wide range of air conditioning units necessitated the use of standard components - compressors, fans, electrical controls, cooling coils etc. The company had 27,000 part numbers (including sheet metal pieces). Most were stock items and were thus first considered for use in a new design. There was an attempt to use the same part on new machines and across machines - to increase component commonality.

6.7 Noon Air Conditioning - Design Structured Interview

6.7.1 Background

Noon Air Conditioning are a small company, with 75 employees and a £5 million pound turnover, producing sterile containment cabinets and rooms for hospital, chemical (including radioactive) and electronic uses. These range in size from single operator cabinets (similar to fume cupboards) to three metres square PVC curtained "rooms". These latter can be fitted together to form larger work areas. Each of these units (cabinets or rooms) is designed to a) supply sterile laminar flow clean air over the work surface thus protecting the "product" being worked on from dust, biological or chemical contamination; b) and, if desired, provide protection to the operator from the product, by the use of negative pressure; c) or to provide both operator and product protection. The cabinets are used in the health, pharmaceutical, chemical, electronic, nuclear, education and biological fields. They are used for the preparation of drugs and radioactive tracers, the mass production of drugs, the assembly and processing of silicon chips, and research and development work with chemical, biological and radioactive agents. The company manufacture six ranges of cabinets, a special unit for the preparation of drugs and drips for use in hospital pharmacies and two types of room containment. The range of cabinets comply to different standards of containment. The company make a standard range of cabinets, accounting for approximately 75% of turnover, and special one-off cabinets, roughly a quarter of turnover.

6.7.2 Manufacturing Facilities

Cabinets are manufactured using two different types of material mild & stainless steel for the home and industrial countries market and laminated wood which is being switched from the home to the developing countries' market. The company's factory is thus divided into two sections, the timber shop and the metal shop. The timber shop has the most machinery in it, saws, a gauging/milling machine and drills etc. Wooden cabinets are manufactured by the company in-house. For this reason the margin on them is higher than the metal products. The company hence wishes to maintain the timber side of the business even though its industrial countries' market is declining. The only machinery in the metal shop is the test equipment. The company only assemble the finished metal cabinets, the fabrication of the cabinets is subcontracted out. Most of the company's products consisted of bought-out components, only the timber cabinets were made in-house. Thus the principal manufacturing operation was assembly.

6.7.3 Market and Industry Issues

The company's domestic market has changed, it now requires the cabinets to be made from steel - with certain parts stainless. The traditional timber material is thus less popular in the home market. The company are thus pursuing a strategy of exporting the timber cabinets to the third world (Saudi Arabia, Pakistan) - to maintain the present capacity. The other export market (Australia, Germany, Ireland and Switzerland) were due to sporadic orders. A distributor network would be needed to increase the volume in this market. It was also intended to export the metal cabinets not just the wooden ones. The company's domestic market is made up of hospitals and clinics, drug and chemical companies and electronic companies and educational and nuclear establishments. The state sector, hospitals etc., is suffering a slow down at the moment, whereas the industrial sectors, particularly the electronic, are growing.

The reason the company made specials, ie. one-offs, was due to its size. If the company were smaller then they would just do specials. On the other hand, if the company were large (like a multinational), they would just produce standards - on a worldwide scale. As the company is in the middle of these two sizes it cannot sell enough standards and, therefore, it needs to manufacture specials. The margin on specials was 10% more than standards but in practice remedial work resulted in the margin being roughly equal.

6.7.4 Design Work

The company's design work is thus of two types - standards and specials. Design work for the standards occurs only when new cabinets or ranges are introduced. Design work on specials is carried out all the time. On specials a co-development programme would be entered into with the customer. General layout drawings would be sent to the customer followed by manufacturing drawings. The customer would then look at the shell - the company would possibly build a mock-up to test the ergonomics. The company always tried to be co-operative, they can build a mock-up in a day and will even allow it to go to site. This programme has been successful in reducing modifications during production.

When a new standard product is introduced a specification is written. This draws heavily upon national standards, the DIN standards, British and American standards and market requirements. Production and production engineering personnel would not be involved in this process. The technical director of the firm (the interviewee) was wary of what the sales department said were the market requirements. This was because they usually supplied copy-cat ideas (ie. features present on newly introduced competing designs) or supplied the requirements for meeting the large orders they had gained. Both of these tendencies stifled innovation. The company had also experimented with innovation - they had tried to replace the fan speed controller, a variac, by an electronic one. The advantage here would be two fold, first the reduction in weight, size and cost of the speed controller (as variacs are heavy and bulky electro-mechanical devices). Second, the air pressure across the filter could be electronically controlled with an electronic controller whereas it could not with a variac. This would mean that the continual manual adjustment the cabinets required would be eliminated giving maintenance and ergonomic benefits to the product. Unfortunately, the company had found that the electronic (triac) controllers simply could not make the fan motors work properly. They were thus stuck with variacs until an electronic controller (possibly a switch mode controller) became available.

6.7.5 Design - Production: Organisation Structure

Since the company responded to the questionnaire (May 1990) and the interview (July 1991) the design function had been reorganised. Previously the design function, headed by the technical director, was divided into the design office and a (new product) development function. It had been found that the company was devoting its whole design effort to current requirements and it did not have the time for product development and hence the design function was reorganised into standard and specials divisions. The previous technical director designate was replaced by the current one during this reorganisation. The specials section is headed by a designer and contains a designer, and two sub-contract personnel - a detailer and a designer. The standards section again headed by a designer contains a timber designer and a trainee issues clerk. There is no production engineering function within the company, neither within the design or production departments. The designers were said to be qualified by their experience in the industry.

6.7.6 Design - Production: Co-ordination

Co-ordination between design and production was achieved through a "loose" project team and informal consultation. The technical director would lead the project team and, in fact, would prepare most of the initial design drawings and technical calculations of air flows. These would be passed onto a second designer for further detail work and then sent to the shopfloor for the construction of a prototype. It was at this stage that questions as to the best way to make the design would be tackled. The designer would visit the shopfloor and liaise with the production personnel. The prototype would be sent for statutory trials before the new product was launched at exhibition. Any problems which arose would be solved by informal consultation - formal meetings, either at regular intervals or at milestones, were not held. The company had found one benefit of the switch to steel cabinets was the involvement of the fabrication firms in the design process.

The company is also implementing BS 5750 by employing a consultant one day a week. They need three manuals - drawing, drawing office procedure and design validation process manuals. There is not much customer push for the use of procedures, but the company are anticipating that it will come from big customers in the future.

6.7.7 Design Process and Manufacturing Considerations

This involvement of a fabrication firm in the design process had enabled the firm to halve the cost of the fabrication of one of their cabinets. The fabricator drew on his expertise to make the design of one cabinet easier to make. This reduced the £2,000 cost by £1,000. The company did not pass on the concomitant price reduction to customers, instead they maintained prices on one unit and intend to reduce the price of a second to increase its volume sales. At the same time as the reorganisation the company, at the prompting of the managing director, had embarked upon a Value Analysis programme. Two products (the one of which was derived from the other) were value analysed. It was determined that welding was the most expensive operation of their manufacture. It was decided to replace continuous welds (very expensive and requiring skilled labour) with stitch welding (cheap and unskilled) the cabinets then being sealed with sealant. Continuous welds were used by the previous design regime for quality reasons. Also the number of welds was reduced. Further, the amount of dressing-off of welds was reduced. Value analysis was also applied to box sections and aerodynamic features, both of which saved money. Materials were also analysed and where previously aluminium was used (for weight saving) mild steel was used (the weight saving not being necessary). The reason why value analysis had made such improvements was due to the over-the-top design and quality of the previous design regime.

As indicated earlier manufacturing considerations were only considered late in the design process, the majority in the pre-production phase. Only production processes were considered during the prototype stage.

6.7.8 Analytical Issues

The company was low on modification, 0-10%. This good performance was not borne out by the behaviour of the firm. The firm manufactured a high proportion of specials, there were thus fewer design faults (by definition each one is individually designed). There were always problems on the shopfloor. Holes were in the wrong place and new ones had to be drilled. Thus fitting provided quite a few modifications. Design changes included having to stiffen things up structurally as the firm did not have a stress department. The problem with the adoption of techniques like design for assembly was the lack of time, particularly on specials, to carry them out. On new products scrutiny meetings would be held in an attempt to reduce modifications. The use of mock-ups on specials had reduced the amount of modification.

Although the value analysis produced some good results it did not result in an increase in standardisation. This could only really be done through the introduction of new products.

6.8 Design Structured Interviews: Discussion & Analysis

This section presents the analysis and findings of the design structured interviews. This consisted of the comparative analysis of modification and standardisation. The intention here was to follow the same approach as the CAD structured interviews and compare pairs of firms using their performance on the measures of modification and standardisation. Hence, the critical factors determining firms' performance would emerge if closely matched firms were compared. First, the comparison of the matched pair of firms is presented, in order that the findings and conclusions that emerged from the rigour of the methodology can be seen. Second, a cross comparative analysis of these two issues across all the design structured interviews is presented. This latter allows comparisons across type of product, product range and company size to be made. It also goes some way to overcome the inadequacy of the matches, as firms differing on product but equal in size can be compared. The findings of the comparative analysis are presented below, firstly modification.

6.9 Modification - Comparative Analysis

Comparing the two pump manufacturers shows that Alef paid more attention to production aspects right through the design process, Beh only considered production once - late in the design process. Although they both have the same amount of modification Alef were more aware of production considerations whereas Beh had only just employed a production engineer responsible for co-ordination. At a guess Beh's good performance was due to this new production engineer. Nevertheless, their good performance was underlined by their policy of reviewing design changes for the impact upon design and production. The modifications which did arise, arose from specific problems with pumps or processes and were not general. Alef's more consistent, wider and longer consideration of production would lead to other benefits than just low modification, such as reduced lead times, better quality etc.

Jeem Agricultural Machinery were low on modification this was due to the maturity of their business and their designers' extensive knowledge of the company's manufacturing facilities. Sheen were higher on modification, this was due to their previous policy of over designing products and maintaining a rigid separation between design and production. Having realised the non-viability of this strategy they had changed it to pursue a more participative and integrative design process, their modifications could thus be expected to reduce. This new policy involved a design change procedure and regular design - production review meetings, coupled with a strategic review of design progress carried out by the directors.

Comparing Meem and Noon air conditioning was problematic due to the difference between their products. Noon were primarily low due to the simplicity of their product, even the complex part - the air filtration - was performed by a simple fan and filter combination. Meem, on the other hand, not only had a complex product - a full air conditioning machine - but also manufactured a wide range of machines. Meem's modification was thus higher at 11 - 20%. The unusual feature of Meem was their attention to quality through the application of Total Quality Management (TQM). This meant that there was a high degree of interaction between design and production functions throughout the design process. Secondly, during prototype construction and production improvements and adjustments arising on the shopfloor were given full attention by the integrated engineering department.

6.10 Modification - Cross Comparative Analysis

The cross comparative analysis of modification shows that for the design structured interviews the determinant of the level of modification was the complexity of the product. Three of the four low modification firms had simple products: pumps and contamination free cabinets. Firms with higher modification, 11 - 20%, had more complex products: agricultural machinery and air conditioning. The anomaly was agricultural machinery where both firms had relatively the same degree of complexity of product and differing amounts of modification. This was because Sheen had tended in the past to over-design their products and not pay enough attention to their manufacture - resulting in the commercial failure of a machine. Sheen had adopted a new management strategy which was producing results and would probably bring them into line with Jeem at 0 - 10%. This strategy of design - production review meetings and encouraging design - production informal consultation was critical to their improvement in performance. This was underlined by the TQM approach of Meem where, again, management placed an emphasis on design - production cooperation and its management. It was this management excellence that allowed them to minimise the modifications which would have otherwise arisen given the complexity and wide range of their product. Hence, it can be concluded that management factors explain the pattern of modifications of the design structured interview firms.

6.11 Modification Comparison: Conclusion

The comparative analyses of modifications has shown that a) the more simple a company's product the lower the modification; b) full and lengthy consideration of production during the design process improves modification (Alef and Beh); c) management of the design process is crucial to minimising and improving modifications; d) design - production review meetings; and e) TQM as a catalyst towards closer design - production integration. The management factors (b to e) meant that firms applying them would not only benefit from reduced lead-times and design expense, but also better quality products. This concludes the analysis of modification, the next section discusses the analysis of standardisation.

6.12 Standardisation - Comparative Analysis

The second issue investigated by the structured interviews was standardisation. The discussion follows the same format as the modification analysis, with comparative and cross comparative analyses. Alef Pumps had higher standardisation, 61 - 80%, than Beh Pumps, 21 - 40%. Alef had standards for all their components, a non-standard component was a modified standard component. They also used standards where they existed. In fact customers could use the ISO 9000 standard to specify the pumps they required. Beh, though, had lower standardisation due to their policy of expansion by acquisition. They too were developing ISO 9000 standard pumps and wanted to lift standardisation to 60%.

Jeem and Sheen agricultural machinery manufacturers had the same level of standardisation, 21 - 40%. Both companies had standards and preferred lists. Jeem had introduced standards for pin joints and materials coding. They also had a bill of materials. Sheen had made an effort to standardise components within and across machine ranges.

Noon Air conditioning had higher standardisation (81 - 100%) than Meem (61 - 80%). This was because their product was simpler than Meem's and had fewer variants. Also it was an old product range - as no new products had been introduced, which if they were would decrease standardisation. This completes the comparative analysis of standardisation. The next section considers the cross comparative analysis of standardisation.

6.13 Standardisation - Cross Comparative Analysis

Comparing the structured interview firms across one another produced the following results. Noon Air Conditioning had the highest level of standardisation which was due to their simple, narrow and relatively old product range as compared to the other structured interview companies. Beh pumps stood out as being low due to their policy of expansion by acquisition and thus their lack of opportunity for component rationalisation. Alef, by comparison, had a high standardisation due to the unchanging nature of the product, pumps, and its technology. The other high performer Meem Air Conditioning had high standardisation due to its commitment to total quality management and its consistent and continual consideration of production aspects during the design phase. Jeem and Sheen agricultural machinery had the same low level of standardisation due to the changing nature of their products, each machine range had to be continually updated for the firm to remain competitive.

6.14 Standardisation Comparison: Conclusion

It can be concluded that the amount of standardisation in the design structured interview firms was determined by the following two factors. First, high standardisation was achieved for companies with simple products, narrow product ranges and unchanging product technology. Second, management commitment to total quality management and consistent and continual attention to production considerations throughout the design process. It was this latter factor which determined that the company with a highly complex and wide product range (Meem Air Conditioning) had as high standardisation as a company with a simple and unchanging product (Alef Pumps).

The usage of standardisation of products as a measure of design performance, while producing interesting results, was not effectively able to distinguish between good and bad performing firms. This was because other factors, independent of management's ability to influence standardisation were at play, notably the simplicity and narrow range of product and the unchanging nature of product technology and market needs.

CHAPTER 7

DISCUSSION

This chapter presents the summary of the findings of the research and some discussion which leads on into the conclusions drawn in the next chapter. It is designed to refresh the readers mind before leaping into the conclusion, it may, therefore, be safely skipped.

7.1 Design

The survey showed that the overwhelming majority of mechanical engineering firms carried out the design of the products they manufacture. Again the overwhelming majority of firms carried out engineering design in-house, with a majority carrying out aesthetic design in-house.

The overwhelming majority of mechanical engineering firms have design departments. Half of firms had development departments and 40% had R&D departments. It can be concluded that design was well institutionalized for the majority of mechanical engineering companies. Hence, it can be inferred that most companies had found that the amount of design work they were carrying out necessitated that the activity be formalised and institutionalised with the creation of a design department.

The majority of all firms in each size band designed their own products, with only the smaller firms (less than 50 employees) being more likely not to design their own products. Hence, size did not determine whether firms designed their own products or not.

The first measure of design intensity, new products introduced per year, showed that most firms introduced one product per year. Significant proportions of firms introduced two and three products per year.

7.2 Product Specification

It was found that the majority of firms drew up a product specification. In terms of regional distribution the analysis showed that regional location did not influence firms in compiling specifications. Firms with more than 50 establishment employees compiled product specifications, firms smaller than this were less likely to. Subcontracting was confined to firms with less than 200 establishment employees. The overwhelming majority of firms with sales turnovers over £2 million drew up specifications. The smaller firms tended to supplement written specifications with verbal instructions, 15% using verbal only specifications. There was a mild tendency for no specification to be drawn up as production equipment age rose to 30 years old. The process technology used by firms did not determine specification compilation, although, a third of one-off producers did not have specifications. The type of product (final, intermediate, both or consumer) was not found to influence product specification compilation. The number of new products a firm introduced per year did not influence the use of product specifications. The majority of firms compiled a written product specification (55%). Forty two per cent of firms used verbal and written product specifications. Only three per cent of firms used a verbal specification. Establishment size only influenced the compilation of product specifications in the case of small and very small establishments where verbal specifications became more prominent. Firms with new production equipment used only written specifications, there was no difference for firms with older equipment. Process technology did not determine which format of specification was used save in the case of mass production.

Two measures of design effectiveness were used to determine firms' performance. The analysis of the first, standardisation, produced ambiguous results. Do firms with written specifications (as opposed to both written and verbal) have higher standardisation, or do firms with higher standardisation find it easier to have written only specifications? The survey data, unfortunately, did not allow this question to be resolved. It was decided not to resolve this issue in the structured interviews. The other measure of design effectiveness was modification. At higher levels of modification it is better to supplement written product specifications with verbal instructions to reduce the amount of modification. At low levels of modification it is slightly better not to supplement written specifications.

The most important aspects that firms considered in their product specifications were functional and engineering requirements along with product cost. Fewer than a quarter of firms considered production aspects in the specification. Thus the pulling forward of the design process was not detected by the survey. Only a small minority of firms considered the later, production aspects, in the early phase of compiling the product specification. The majority of firms extensively involved design management, sales, marketing and designers in the drawing up of the product specification. The priority accorded to the involvement of design management points to firms specifying products in wider terms than a purely narrow design or sales perspective. However, the expertise and knowledge of production personnel are not included in the product specifications drawn up by companies.

7.3 Organisation & Co-ordination

The most frequent organisation structure was simultaneous engineering. Firms were equally split in the use of matrix organisation and integrated product-process design departments. The majority of firms used meetings as the design co-ordination mechanism. Project teams, product champions and ad-hoc consultation/visits were each in use by nearly a half of firms. Liaison officers were hardly used at all. Project teams were used by firms with more than twenty employees, and especially in large firms. Conversely ad-hoc visits were used more in smaller firms but were still used in large firms. Ad-hoc visits/ consultation was used across the size range. There was a switch in the use of meetings, used more below ten million pounds turnover (ie. small firms), and product champions, used more above ten million pounds. It is concluded that meetings within the framework of simultaneous engineering were the most frequent design - production management arrangements.

Designers, sales, production engineering, production management and design management were the personnel most heavily involved in design - production co-ordination. Involvement was not significantly influenced by establishment size.

Design reviews were held by most firms. Production engineering involvement was limited to only having a say in the design. Most firms, however, had good co-ordination between design and production. Factors which hindered co-operation were different expectations, departmental barriers and physical separation. Improvement factors were common expectations, removing departmental barriers and physical closeness. This analysis implies that the differentiation between design and production departments had created a management problem for firms. Thus, management were still trying to understand the interface between design and production and how to manage it.

The attempt to determine which organisation structures and co-ordination mechanisms gave the best design performance produced ambiguous results. Two measures of design performance were used, the amount of modification during production and the number of standard components in a design. Firms with an organisational structure of integrated product-process design departments performed only marginally better than simultaneous engineering and matrix organisation. Standardisation produced clearer results. It showed that integrated product-process design departments produced higher levels of standardisation than the other two structures. Simultaneous engineering was shown to be a worse performer on standardisation than matrix organisation. The co-ordination mechanisms of meetings, product champions and project teams again gave only slightly better results. The inclusion of sales personnel was shown to increase firms' performance, whereas marketing did not.

7.4 Consideration of Production

The most important production aspects considered in the conception design stage were product cost, development cost, functional requirements and materials. During detailed design the important aspects were engineering design, styling, standardisation, materials and to a lesser extent production processes. During the prototype stage production aspects were most important. During pre-production labour requirements and production control were the most important aspects. This shows that the manufacturability of the product is not considered until after it is designed. Thus, the effective and efficient manufacture of the product is not given sufficient attention by mechanical engineering firms.

The research found that production engineering were more extensively involved in the design process the closer it moved toward manufacture. Extensive production engineering involvement during detailed design was confined to a third of companies. Although 60%, or so, of companies had some involvement of production engineering during this stage. By the time the pre-production stage had been reached extensive production engineering increased to 60%.

The research found that the design stages of a product's development could be summarised as follows: The conception stage was when the specification of the product was considered, with some attention given to how it fitted in with existing products and components. The detailed design stage was when the practicalities of the design were worked out - ie the "what to make" was designed. The requirements of production were also given some consideration - ie. production processes and assembly techniques. The prototype stage was where the costs of what was being made were honed, still keeping the product within specification. Now production aspects were given full consideration: the "practicalities of production" - how are we going to make them, how many, on which machines and by whom. The pre-production stage was for making the products and refining the process of making them. Production was focussed on making the products and their quality.

The research into the consideration of production aspects found that the prototype design stage was pivotal - where the balance shifted from design aspects to production aspects. Companies' current practice is thus to consider the manufacture of a product after it has been designed. This has ramifications for the efficiency and speed of manufacture of a product. Production engineering were involved the closer a product moved toward manufacture. Companies should endeavour to consider the production aspects of machinery, labour requirements and plant in the detailed design phase. There is also scope for production to be considered in the conceptual design stage, which at the moment concentrated on the specification of the product.

7.5 CAD

The results for CAD of the survey of the UK mechanical engineering industry, were found to be consistent with previous research. It was found that 58% of surveyed companies used CAD. This, and the regional and establishment size distribution of users were in agreement with previous studies. User firms were concentrated in the South East and West Midlands regions and in the medium and, particularly, large sized establishments. Other characteristics which were found to determine CAD use were: turnover (above two million pounds), production equipment age (less than five years old), process technology (one-off and batch had CAD but not mass/ flow line) and product type (final and intermediate, but not consumer).

Importantly, the survey confirmed the hypothesis that CAD was mainly used for drawing, and in particular 2D drawing, for the industry as a whole. The percentage figures reported for 3D wire frame and solid modelling use augur well for firms realising the full ability of CAD, particularly in the future. The size of firm distribution of drawing showed that the "medium" (200+) sized and large firms mainly account for the use of 3D wire frame and solid modelling. These two types of drawing tended to follow the industry establishment size distribution of CAD use, that is increasing with size. Contrarily, 2D drawing is concentrated in the smaller establishments (less 500 employees). The results of the survey for more sophisticated uses of CAD for design analysis and conceptual design were difficult to interpret. They did show that only a minority of firms claimed to use some form of design analysis. The most significant sophisticated uses of CAD were found to be bills of material and component interference checking.

For CNC machining only a quarter of firms possessed three axis CNC, with the distribution following that of CAD (increasing with size). Most of them were able to simulate machining on the CAD system. Five axis CNC machines were restricted to the large firms.

The analysis of the impact of CAD confirmed the expectation that it is used overwhelmingly during the detailed design phase of design. It also confirmed CAD use during development and its non-use during testing. The consistent use (30% of users) of CAD in the specification and feasibility stages of design indicates that firms are beginning to exploit the full potential of CAD. Also, the achieved benefits of CAD were mostly the straight forward ones of ease of modification and rapidity of design. Secondly, there was only a marginal improvement in the amount of co-ordination and integration between design and production functions as a result of CAD use. This was underlined by the lack of access to the CAD system by production engineering. Hence, CAD was used by the majority of firms in simple applications of drawing, and the benefits that resulted were ease of modification and rapidity of design. If CAD had been applied to more sophisticated applications there may have been greater gains. The gains from the involvement of production engineering in design and using CAD to improve the manufacture of products would produce significant competitive advantages in terms of quality, cost and time. These, however, remain to be realised by firms.

An important outcome of the survey was the finding that CAD had increased the amount of modification carried out to designs after they had been transferred to production. This, when taken together with 30% of firms using CAD in the production stage of product design and the ease of modification benefit demonstrates that firms are changing designs while they are in production. Two propositions follow from this. First, that these modifications during production have a detrimental effect upon the efficiency of manufacture of products, costs, and lead and delivery times. If this is so, CAD far from enhancing a firm's competitive position (presumably the reason for the investment in CAD) can actually harm it. This outcome would be contrary to the expectation of the literature (Arnold & Senker (1982), Blackburn et.al (1985), Campbell & Warner (1988), Ingham (1989)). Or, second, the ease of modification provided by CAD enabled firms to a) improve the product during its manufacture and b) to take account of changing customer needs. This responsiveness to customers would improve the firm's competitive position. This latter proposition would imply that the balance between cost and benefits of design modifications during production has been changed by CAD. The survey did not indicate which of these two propositions was the case. To clarify this structured interviews were undertaken. These showed that CAD had changed the balance between costs and benefits of design modifications - firms were more effectively able to modify designs when the possessed CAD. Both Delta and Upsilon had increased the number of times they could pass through the design loop thus perfecting the design before manufacture started. CAD allowed firms to correct manufacturing problems and respond to changing customer needs more efficiently - saving time and money.

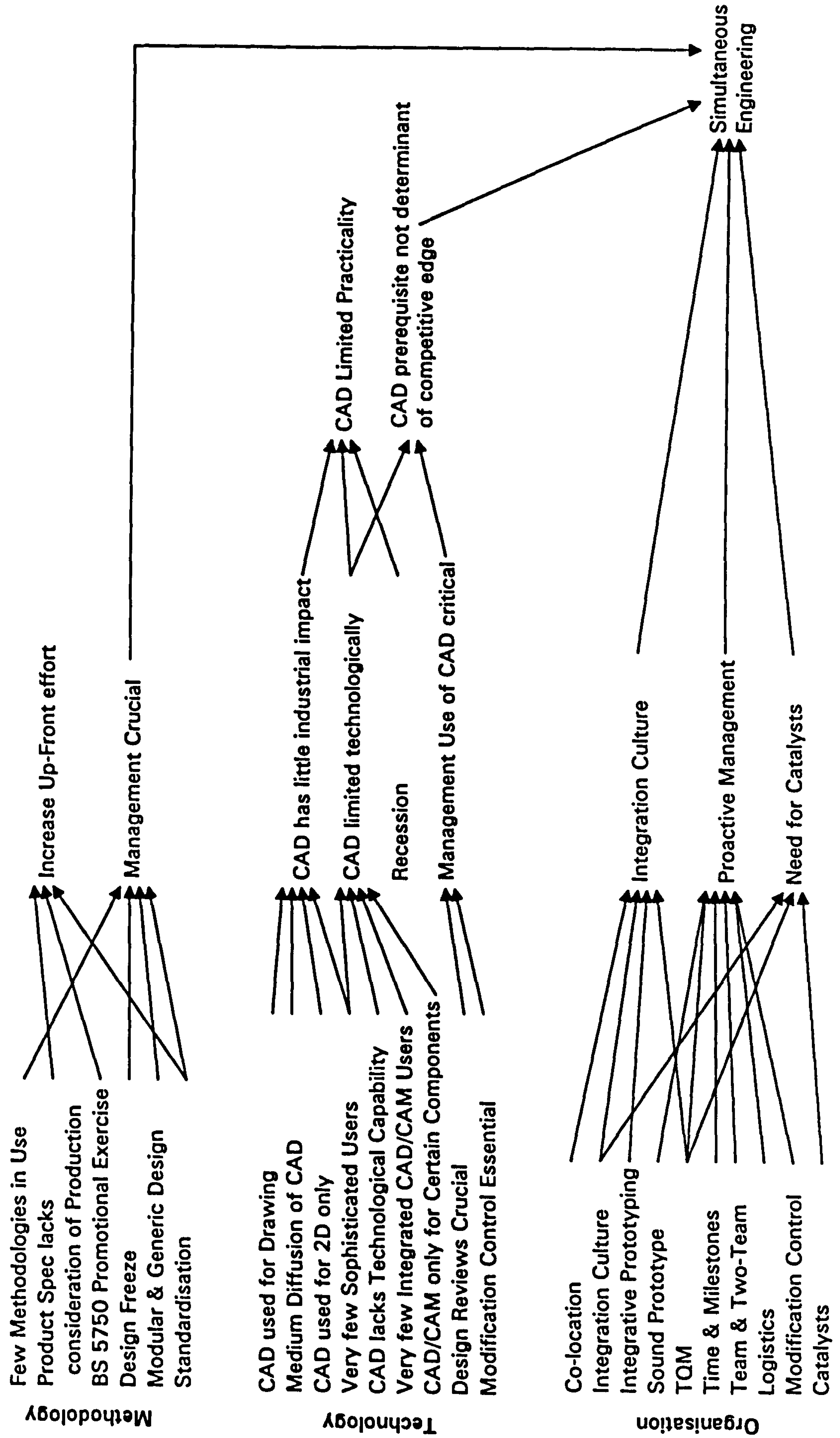
Further research is required on standard components to determine if CAD increased standard components, or if firms with high numbers of standard components were more likely to use CAD. Again the structured interviews would be used in an attempt to solve this question. Further research is also needed to determine just where the benefits of CAD (and their quantification) occur. Unfortunately, this fell beyond the purview of the research and will be left to other researchers. Once this information is available the implications of using CAD simply for drawing, and the failure to integrate it with production for the competitive position of firms will become clear. Only then will managements be in a position to fully appraise the investment in CAD. In conclusion the competitive use of CAD means that management must focus on the whole design process rather than the narrow role of drawing that CAD performs. This necessitates the inclusion of production personnel into the design process and the implementation of management procedures, and mechanisms, such as design reviews. It is these latter management factors that will determine firm's competitive ability. Of course, CAD has gains in speeding and easing the drawing process, but these are prerequisites for competitive strength and not its determinants.

CHAPTER 8

CONCLUSION

This chapter presents the conclusions and implications of the research into the management of product design in the UK mechanical engineering industry. It also presents the recommendations for companies and the directions for future research, as well as ideas which may be of interest to government departments and agencies developing initiatives for companies. The research consisted of a national random survey of the UK mechanical engineering industry. Eleven follow-up case studies were conducted, one set on CAD and the other on product design in general. Each set consisted of matched pairs of firms - comparing good and poor performing firms as measured by design modifications and standardisation. The CAD case studies were on conveyors (Alpha and Beta), machine tools (Delta) and railway brakes (Theta and Upsilon). The design case studies were on pumps (Alef and Beh), agricultural machines (Jeem and Sheen) and air conditioning (Meem and Noon). The conclusions were presented using a framework for the analysis of the design - production interface which was derived from the research. The framework divided solution approaches to the interface into three: methodology, technology and organisation. Each of these approaches can be used to provide integration between design and production. For example, design methodologies such as design for assembly can be adopted, or CAD/CAM can be used or project teams can be set up. Each of these approaches has its weaknesses and benefits. Some of these were identified by the research and are reported in the sections below: 8.4 to 8.6. Further, each approach has two dimensions the internal, that applying inside a company, and the external, that outside a company. This three-fold classification and the internal and external dimensions will be used to review the key findings of the research, and to present conclusions and recommendations. The internal dimension will deal with conclusions and recommendations for companies to adopt and the external dimension will draw conclusions and recommendations for academia, and suggestions for government bodies concerned with industry initiatives.

Fig 8-1 Conclusions Map



8.1 Chapter Summary

This study of the design - production interface in the UK mechanical engineering industry divided the solution approaches to the problem of the interface into three: **methodology, technology** and **organisation** solutions. The key findings from the survey and case studies were used to draw conclusions and recommendations for each of these solution approaches. The conclusions are mapped out in Figure 8-1. The methodology solutions discussed were placing more design effort up-front of the design process, product specification, use of methodologies - Design for Assembly (DFA), Quality Function Deployment (QFD), British Standard BS 5750, design freeze, modular, generic and generational design and standardisation. It was concluded that methodology solutions (DFA, QFD, BS 5750) had little use and impact in industry. It would not be fruitful to devote government support for firms to methodology solutions until the issue of non-adoption has been addressed. Academic research can undertake work to extend the methodologies available and to provide easily adopted methods. Second, management's approach to, and use of, methods for design freeze, generational design and standardisation was the key factor in producing better performance.

The research showed that technology as a solution to the design - production interface is limited for three reasons - (1) its diffusion, (2) the way it is used and (3) technological limitations. Although there is a reasonably high usage of computer-aided design in the mechanical engineering industry, some 60%, this is still not widespread enough for it to fully transform the interface. Second, there is the way CAD is used. Although CAD had the potential to improve large parts of the design process, in for example conceptual and functional design, CAD in the mechanical engineering industry is only used for drawing. Further, most firms are only using the 2D drawing ability of CAD and are not using its 3D capability. The more sophisticated uses of CAD, for design for assembly etc, were not taken up by firms. This means that the real gains of CAD - 3D design and simulating finished products and their assembly before anything is made - are not even approached by companies. Thirdly, there are the technological limitations which were shown up by the case studies. Only Delta and Theta were able, with the use of CAD/CAM and FMS cells, to achieve a high degree of integration between design and manufacture. The survey found that only 40% of firms using CAD also had CNC machines. This means that the integrative ability of CAD/CAM is restricted to roughly a quarter of the mechanical engineering industry. FMS being a more complex and expensive technology can be assumed to be even less prevalent in industry. Thus, only a minority of firms are able to contemplate CAD/CAM integration, let alone achieve it. Second, this was only for a select range of their components and not for the whole product itself (eg. aluminium manifolds). Hence, it can be concluded that the integrative ability of these technologies in practice, as used in industry, is very limited.

It was also seen from the case studies that the difference between the good and poor performing companies was due to their management of CAD and the design process. Companies such as Delta and Upsilon were better because of their management, CAD only being a prerequisite and not a determinant of their performance. To increase the competitive capability of companies through CAD, three things need to be done by firms. First, management need to widen their focus from drawing onto the whole design process. Second, production engineering and manufacturing personnel need to be more involved in design, and particularly in using CAD. Third, there needs to be better overall management of the product design process. Only in this context will CAD produce competitive results. The current recession has further curtailed investment in CAD, meaning its potential is further weakened.

It was shown for the methodology and technology domains that the better performing companies not only used certain techniques and technologies but used them better. This was because their managements paid more attention to integrating the design - production interface. It was concluded that management was the deciding factor. The management approaches which could be adopted were discussed in the organisation solution domain. These were an integration culture, co-location, integrative prototyping and development of a sound prototype, TQM, time & logistics, team & two-team, modification control, and catalysts. It was found that the better performing companies all had elements of these in place. The complacency of firms was jolted by catalysts - TQM, commercial flops, competitive pressures and the recession. It is concluded that firms will only improve their design - production integration when forced to by one of these catalysts. The most appropriate catalyst for this, simultaneous engineering, was not investigated by the case studies. This was because, as with green issues, its importance emerged after the research study had been designed. It is recommended that companies wishing to improve their design - production integration and achieve competitive edge adopt simultaneous engineering.

8.2 Aims & Contribution to Knowledge

The aims of the study were:

1) To investigate the nature of the working relationship between design and production functions in the UK mechanical engineering industry.

2) To analyse this relationship in terms of product design effectiveness.

3) To attempt to produce a general framework for the application of recommendations for improving product design appropriate to different types of companies.

The **first aim** of carrying out a national investigation of the design - production interface in UK mechanical engineering was met by the survey, and forms the first claim to original contribution to knowledge of the research. Such a systematic examination of the management of product design in the UK mechanical engineering industry has never been done before. As mentioned in the methodology chapter, previous research has used narrow samples (size, products and industry) which limits its validity to the firms in the sample frames. The current work, drawn from a random sample, enables more general recommendations to be made. It also allows a wider range of products to be covered than previous research. The **second aim** to analyse the relationship in terms of design performance was also met by the survey. Other researchers have related their study findings to design performance, the originality of the present study hence resting on the fact that this measurement of design performance was done for a national industry.

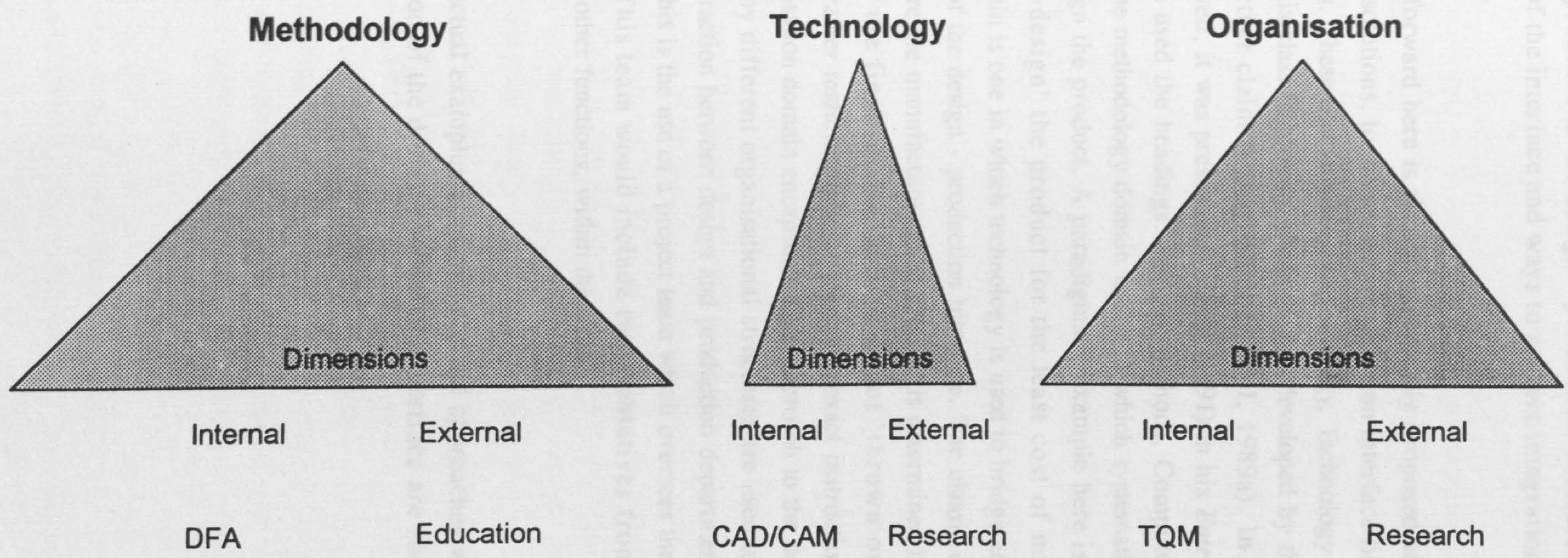
The second claim to originality was the use of a novel methodology - the combination of a random questionnaire survey and two sets of case studies with an analytical bridge between the two. This research design achieved a rigorous and structured methodology. The structure came from the linking of the case studies to the survey, the matching of paired companies and the comparison of poor and good performing companies (as measured by the design performance indicators). The rigour came from the initial random selection of companies, the careful matching of companies and the comparison of good and poor performing companies. This is an unusual methodology which produced interesting results never obtained before. It is better than either a survey or structured interview methodology - combining the best of both and overcoming the limitations of each. It has learnt the lessons of other studies' methodologies. Other researchers have not combined survey and case studies in this way. The only combined methodology is the postal questionnaire and interviews of Potter & Roy (1990). What their study lacks is the systematic structuring or linking of the two methodologies together. Both the matching of firms and the good/ poor comparison have not been used by other researchers. This novel methodology allowed both the elaboration of issues of interest derived from the survey (soft benefit) and allowed the testing of hypotheses derived from the survey to be carried out in a structured manner using matched-pair case studies (hard benefit). Also the cross comparison of case studies across products allowed the generation of further conclusions. The interaction between two such methods produced results which were unique to the current study. It is thus the best methodology, adopted to date, for studying the design - production interface and the management of product design. It also ushered in a rigorous new methodology which other researchers can adopt in their studies.

The **third aim** of producing guidelines to help companies improve product design is dealt with below. These guidelines were developed by applying a theoretical framework to the results of the research. This framework was derived from the literature by the author (Riedel, 1989a). It forms the third claim to original contribution to knowledge. The framework can be used both by researchers in studying product design and by companies - in identifying, evaluating and selecting approaches to solving the design - production interface in their company. Unfortunately, the adopted methodology of a survey questionnaire did not allow the third aim to be fully met. It was not possible to produce guidelines appropriate to different types of companies. It was impossible to divide the survey companies into different types. This was because they were derived at random, the resulting selection containing many varied products - with each product being typically represented by one company. This could not form the basis of a comparison. The drawback of the research was in trying to move from the general to the specific, when in fact the only way to derive general guidelines is in moving from the specific to the general. A suggested possible alternative methodology to do this is to structure the sample by types of product. For example, structured case studies of representative pairs of companies manufacturing different types of products. Thus, complex products, eg. machinery, can be compared with simple ones, eg. gears. This would allow the generation of recommendations which applied to each type of product. These recommendations can then contrasted and compared to produce the desired general framework for product design improvement. Such a framework would then apply to all manufacturing companies. However, even this is limited as industry changes over time. An historical perspective is required which a snap shot stratified sample could not provide. It is very difficult to characterise a whole (changing) industry due to the lack of data. Other researchers have not yet come up with a general framework because of the dynamic environment and the immense difficulty of obtaining adequate data for different scenarios. This methodological conundrum is for future researchers to resolve. It can be said that the third aim was very ambitious. However, it was possible to produce the guidelines in a more general form, ie not applying to specific types of company. These form the fourth claim to contribution to original knowledge, and will be presented after the following section.

8.3 Framework for Analysing the Design - Production Interface

The conclusions are presented using a framework for analysing the design - production interface. This framework, introduced briefly in the theory chapter, was initially developed from studies of the literature. The literature shows that there is a problem in managing the interaction between the design and production departments for the introduction of new products. The competitive advantages to be gained from the rapid introduction of quality new products, matching market requirements, cannot be achieved without there being a high degree of integration between the design and production functions of a company (Gomory & Schmitt, 1988). The resolution of the problem of the separation between design and production, is, therefore, central to the competitive performance of companies. Previous research has characterised this separation as the "design - production interface". There has been a limited amount of work in this area which has attempted to put forward solutions to the problem of managing the design - production interface. This work has resulted in each author only proposing a few solutions, for example: overlapping (Takeuchi & Nonaka, 1986), senior management commitment (Adler et al, 1989), electronic data interchange (EDI) (Hunt, 1991), staff rotation, novel organizational structures & manufacturing sign off (Ettlie & Stoll, 1990) simultaneous engineering (Hartley & Mortimer, 1991). These appear as unstructured and ad-hoc, there being no overall linking concept. Managers and researchers are unable to see how all these various techniques fit together into one picture. The previous research also suffers from a narrow perspective, concentrating on particular aspects or techniques. This has prevented a more holistic, and comprehensive, view of the design - production interface from being adopted. The proposed framework provides the cohering and linking concept, bringing conceptual and practical clarity to the design - production interface. The confusion, fragmentation and isolation of existing approaches means that the fundamental problem of the design - production interface remains.

Figure 8-2 Solution Domains to the Design - Production Interface



The theoretical framework put forward here encompasses the totality of solutions and solution approaches to the design - production interface. With it a fuller understanding of the interface and ways to achieve integration across it can be better developed.

The theory put forward here is that the previously proposed solutions, and any potential future solutions, to the design - production interface lie in three distinct solution domains. These domains are: Methodology, Technology and Organisation (Figure 8-2). This classification of solutions was developed by the author in 1989 and forms a further claim to originality (Riedel, 1989a). In fact others have identified it as well, it was presented by Hunt (1991) in his *Enterprise Integration Sourcebook.* He used the headings: Formal Methods, Computer-Assistance and Management. The methodology domain is one in which systematic design methods are used to design the product. A paradigmatic example here is the use of value analysis to 're-design' the product for the least cost of manufacture. The technology domain is one in which technology is used to bridge and, in some cases, eliminate parts of the design - production interface. The classic example of this is CAD/CAM where the manufacture of the product is determined by the CAD/CAM system. Thus, the final product design is not 'thrown over the wall' to manufacturing, rather manufacturing is given the exact instructions to produce the item. The organisation domain encapsulates the approach to the design - production interface whereby different organisational structures are used to manage and co-ordinate the interaction between design and production departments and personnel. An example of this is the use of a project team which oversees the introduction of a new product. This team would include representatives from the design and production, and other functions, within the firm.

The practical/ actual examples of techniques and approaches which fit into this conceptualization of the design - production interface are shown in Table 8-1 below.

Solution Approach		
Methodology	*Technology*	*Organisation*
DFA	CAD/CAM	Project Teams
DFM	FMS	Matrix Organisation
QFD	FEA	Product Champion
Design Procedures	EDI	Project Management
Value Analysis	DFAA Expert Systems	Simultaneous/Concurrent Engineering
BS 5750/ ISO 9000	CAD Kinematics	Co-location
Product Specification	DNC	Liaison Officer
Design Review	Rapid Prototyping	Ad hoc Consultation/visits
Design Freeze	CIM	Sequential Engineering
Standardisation		Production Co-ordinator
Generic Design		Staff rotation
Modular Design		Two-Team
Generational Design		Lightweight to Heavyweight Product Manager
Group Technology		Integrated Product-Process design dept
Taguchi Methods		Integration/Coordinating Department
Manufacturing sign-off		Integrated Prototyping
BS 7000 Product Design		TQM
FMEA		Modification control/rolling-up changes
		Milestones
		Integrated Product Development
		Secondment

Table 8-1 Classification of Solutions to the Design - Production Interface

This conceptualisation of the design - production interface is novel because it distinguishes between three distinct solution domains of the interface. It also concertises the concept of the design - production interface into three parts. This is important in terms of product design in industry and in terms of further technical research - such as CAD system development or design methodologies - but also in terms of future academic research on product design and the design - production interface. Importantly, this theory conceptualises the design - production interface as a whole rather than, as with previous research, just parts, or segments, of it. It thus allows the interaction between the three domains to be explored within one conceptual framework. This is particularly important because the use of new design methodologies, or technologies, has to be integrated with the organisation and management of product design. Research into the former domains must take on board the latter, organisational and management, implications of these domains in order that effective recommendations for the introduction of new products can be made.

It is noted here that each of these domains can be conceived of as having two dimensions: solutions which apply within the firm (internal) and solutions which derive from outside the firm (external). The external dimension encompasses the academic and technical research carried out, independent of individual firms, which results in solutions to the design - production interface being put forward for use within firms. It is consists of the policy environment of firms - government and the European Community etc, and the education of designers and engineers. These two dimensions will be used in the rest of the conclusion.

A further refinement in the presentation of conclusions is that between general and specific conclusions. For instance, it was concluded, in general, that management was the most important solution domain. Within this, however, a number of specific conclusions and recommendations were also made (see below). The next three sections present the conclusions and recommendations using the logical framework derived above, starting with methodology.

8.4 Methodology Solutions

Methodology as applied to design has been defined by Gasparski (1989) as the theoretical reflection on the design process. That is, it deals with the analysis of the purpose of design, defining its essence and analysing the procedures applied in the process of design, the practice of designing, instructions for designing, including 'methods of design' and the individual actions involved in creating a design (ibid p154-5). Methodology solutions to the design - production interface aim to provide the design team with procedures or methods for designing for manufacture and/or information about the manufacturing process. This involves a choice of either a) solutions internal to the firm or b) those external to it, but for use in it. Solutions internal to the firm include providing the designers with the relevant knowledge of manufacturing processes, by recruiting production personnel as designers, or educating designers about manufacturing processes. External solutions apply the classic method of codifying and recording the nebulous expert knowledge of individuals engaged in manufacture into principles and guidelines regarding design for manufacture. This knowledge is then written down in the form of manuals and sold for use in firms. The biggest and best example of this is scientific management/ work study, wherein a method is applied to the analysis of work to make the carrying out of the work more efficient. One of the best known methods is Boothroyd & Dewhurst's *Design for Assembly Handbook* (1983). Other examples include: *Newnes Electronics Assembly Handbook* (Brindley, 1990), *Bearings & Lubrication. A Mechanical Designers' Workbook* (Shigley & Mischke, 1990), also covered in this McGraw-Hill Mechanical Designers' Workbook series are machine design fundamentals, distortion and stress, corrosion and wear, fastening, joining and connecting, gearing, mechanisms, and power transmission; the McGraw-Hill Printed Circuits Workbook Series includes: engineering, fabrication (Coombs, 1990), soldering, assembly, testing, quality and reliability, and multilayer and flexible circuits. There is also the Design Science/ Method attempt by Jones (1970) and his followers to develop general frameworks for design.

A grey area emerges when design for assembly is considered and in particular the use of computer programs (or expert systems) for DFA. Obviously, the use of computers inclines one to include DFA methodologies using computers as falling into the technology category. This, however, would be false as the computer has merely automated the use of a methodology (DFA). The foundation of the approach rests upon method. Technology, properly, is a bridging technology - it bridges design and manufacturing physically. Expert systems and other computer

DFA programs rely on the elicitation and encoding of human expert knowledge into a computer processable form. Thus, the source of the knowledge, and thus of the approach, comes from the manually derived methods for achieving DFA etc. Once computerised the result is an automated method. This does have the advantage that it can improve upon the expert knowledge (by being more systematic in applying reasoning on the knowledge and the problem to be solved). It can thus be more effective than human experts (Swift, 1987).

The major limitations of the methodology approach are: 1) It does not take account of changing production technologies. This is especially the case with internal solutions. Designers would not be able to keep up with all the latest changes on the shop floor. 2) Designers' knowledge of manufacturing would remain at the abstract level of general principles and would not adequately reflect the actual production techniques in use on the shop floor. This limitation would be somewhat reduced if the second option of recruiting manufacturing personnel into design were followed, at least the gap between actual techniques and designer knowledge would be reduced - if not eliminated (it may not be).

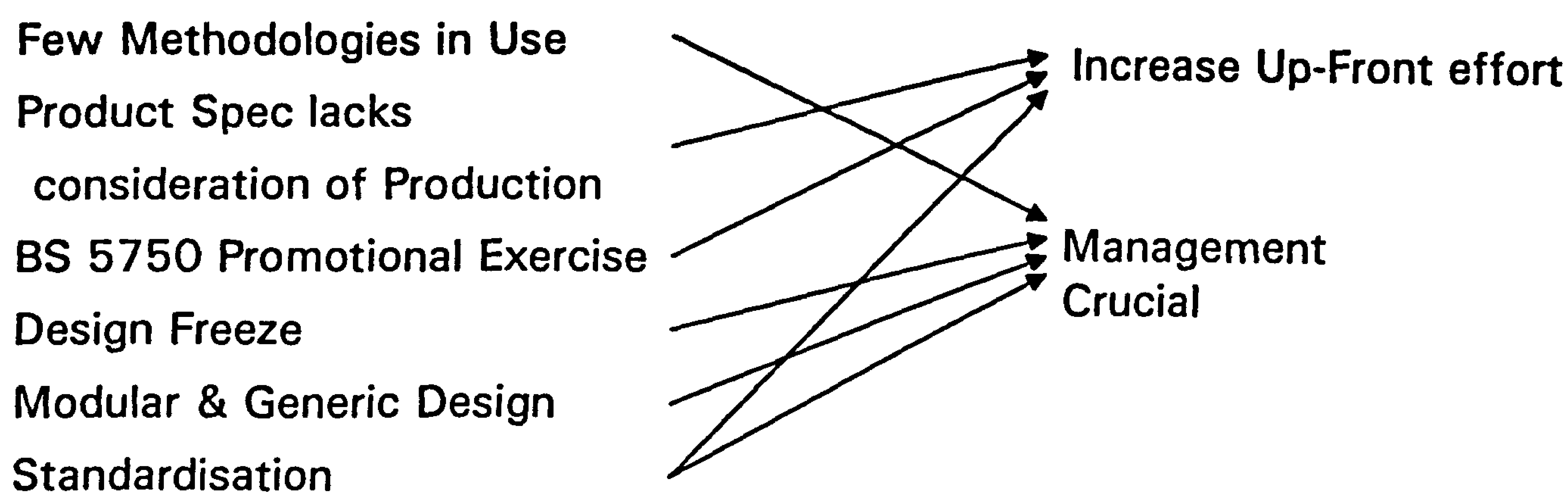
External solutions have the problem that they would not reflect the actual production techniques in use within the individual firm and thus their written advice would have to remain at the general/ abstract level. This limitation could only be overcome by providing a systematic methodology that included enough factual detail of manufacturing operations to enable designers to successfully design for manufacture. Note this detail need not consist of descriptions of manufacturing operations and how to optimize design using them (including eliminating certain manufacturing operations). Rather, emphasis should be placed on the systematic methodology of the approach. The big benefit that the methodology approach has, which the others do not, is that it requires no reorganization of the design/ production interface. Thus it would be compatible in all industrial firms and would not encounter the structural barriers that the technology and organisation approaches undoubtedly entail. As it was methodology, for some of the above reasons, was not centrally put under the investigative microscope of this research, nevertheless some conclusions can be drawn.

The methods for achieving integration can be divided into three types. (1) Those that are concerned with design, (2) those that integrate between design and manufacture and (3) those concerned wholly with manufacture. The design group consist of the product specification, modular product design, generic product design, design for adaptability, failure mode effect analysis (FMEA), value analysis and design freeze. The integrative group includes design for assembly (DFA), design for manufacture (DFM), and quality function deployment (QFD). The manufacturing group include material requirements planning (MRP), manufacturing resources planning (MRP II), just in time (JIT), optimised production technology (OPT), statistical process control (SPC), value analysis and Taguchi methods. These latter manufacturing techniques will not be discussed here as there is plenty of literature and best practice examples to refer to. SPC and Taguchi methods are techniques for ensuring and improving the quality of products manufactured. This leaves design and integrative methods to be discussed.

8.4.1 Up-fronting the Design Effort

It was seen earlier that the early design stages are where the crucial decisions concerning manufacture are made, determining for example product cost. The concentration of effort early in the design stage is referred to as up-fronting the design effort. The research found that the key design stages were conception, detailed design and prototype. Research attention needs to be paid to these key stages. The survey indicated that the prototype stage is the pivotal stage where attention shifted from the practicalities of design to the practicalities of production. Companies thus consider production after product design. Further, research is needed to identify just what the production aspects that were considered during the prototype stage were (this research found assembly techniques, production processes, plant and machinery were considered). Then, methods and techniques for moving their consideration earlier in the design process need to be developed. The approach of Hollins & Pugh (1990) on product status can be used in this. Also the conception stage needs to be researched to determine why production aspects were not considered then. Such research could identify which production aspects (this research found existing products, materials, standardisation and product quality) were considered and how those not considered could be. The production aspects of production processes, assembly techniques, plant and machinery could be given, at least initial, consideration in this stage. In the detailed design stage assembly techniques, plant, machinery and labour requirements could be considered. As to a research method to be adopted it can be observed that Souder's (1987) approach - the identification of successful and failed product ideas - is not the model to follow. As the successful use of a vocabulary of 10,000 words (or set of ideas) from a dictionary of 70,000 words (ideas) tells us nothing. One set of words can be just as good as another. Rather, it is better to focus upon the implementation of product ideas - how are product ideas implemented (designed), what determines successful implementation, and how can ideas be better implemented. It is hoped that this thesis has made a good attempt at answering that question, and provided a strong spring board for further research.

Fig 8-3 Methodology Conclusions Map



8.4.2 Design & Quality Methodologies

There are readily available techniques for DFA and DFM and yet they are not taken up by firms. Very few methodologies were reported as being in use by firms. Those that were, for example TQM, were not used by a great many firms. The findings of the CAD survey showed that 40% used design for assembly. However, the case studies showed that this was not automated DFA, rather that DFA was carried out manually on the CAD system. Only three structured interview firms were actually using automated design methods: Jeem Agricultural Machines for linkage kinematic design and Delta and Upsilon Machine Tools for finite element analysis. The only other methodology in use was a quality one - BS 5750. This had been adopted by several of the structured interview firms. There were, however, two important limitations. First, BS 5750 is itself limited. Quality is about improving the quality of the goods one produces, which requires a constant striving for quality improvement. BS 5750 simply requires firms to write a procedure manual which documents all their existing procedures. It does not require firms to improve upon these procedures, devise new ones or redesign them to improve quality, or even to improve the quality of their products. There is also no enforcement or development of these written procedures, merely documenting one's existing poor performance is sufficient. BS 5750 is simply an attestation that firms are using satisfactory methods (procedures) to produce products. Second, the reasons firms gave for adopting BS 5750 were not to do with improving quality but rather in order to pre-emptorily assuage their customers - to demonstrate to the market that they were a professional firm. A survey of 202 UK manufacturing companies carried out by IBM and London Business School found that adoption of BS 5750 did not in itself guarantee any improvement in quality performance (Hanson & Voss, 1993). Thus, BS 5750 was adopted by firms not to improve product design or competitiveness, but simply because their customers desired it - a promotional exercise in other words. The low level of use of methodologies was confirmed by Trygg's (1992) survey of large Swedish manufacturers. DFA was used by 19% of firms and QFD was used by 31%. A 1986 study of the 135 largest Japanese manufacturers revealed a 50% QFD usage (ibid). Hence, research is needed to identify why firms have not adopted these methods. This would need to consider how companies acquire the techniques, how to raise awareness of them, how to adapt them to a company's specific use, how to use them, how to optimize them and how to make them accessible - particularly for small companies. The question of affordability of the techniques needs to be addressed by research into assessing their benefits, perhaps following the methodology of Potter et al (1991). The initial resources invested in design for assembly have to be compared to the payback from quicker assembly, the financial benefits, time compression, ease of accessibility (for ease of assembly, ease of service), freeing of downstream resources for use elsewhere, and the benefits of being earlier to market making one competitive.

8.4.3 Product Specification

One key way to speed things up is to be sure of what you want before you do it. Thus the product specification - the definition of the product - is the part of the development process where a great deal of effort should be directed as the benefits of this effort are great. This effort has to come before any other design or production activities hence the concept of front-ending introduced by Hollins & Pugh (1990). They discuss a number of techniques for front loading the design process, prime among them defining the product - the product design specification. It was seen from the survey that most firms draw up written specifications, the minority supplementing them with verbal instructions. The most important aspects firms considered were functional and engineering requirements, and product cost. Fewer than a quarter of firms considered production aspects. Design management, sales, marketing and designers were most heavily involved in compiling specifications - production personnel were absent. Hence, their expertise and knowledge were not taken into account at this most crucial stage of the design process. It can be seen that there is scope for improving the consideration of manufacture in the product specification. Due to the work of Hollins & Pugh and that of the author (Pawar & Riedel, 1990) on the product specification and the emergence of the importance of CAD it was decided not to investigate the product specification in the case studies.

8.4.4 Design Freeze

After a design has been specified inevitably there follow a string of modifications, some minor others major. These are meant to improve a design or its manufacture, however, each one costs money and holds up the development process. It is thus important to control these changes and not allow them to get out of hand. Currently there is no suitable formal process for monitoring the maturity of a design, or a metric for measuring design maturity. Design management should take the mantle for assessing design maturity and declaring a "design freeze". Design freeze is extremely important for achieving time to market. Without it changes can be made right up to launch and hence delay launch. In order to freeze a design its maturity should be monitored by a formal procedure. Only Meem Air Conditioning had an explicit design freeze procedure. Once a design was frozen changes would be rolled-up. The issue of measuring design maturity is one requiring further research. This would be a fruitful one, helping companies to objectively freeze their designs rather than when they feel like it - when it is usually too late.

8.4.5 Modular & Generic Design

Modular and generic product design are two techniques of importance in integrating both design and manufacturing. Modular design means dividing a product down into a number of modules each of which is independent of the others. Thus a module can be improved or redesigned without affecting the manufacture and design of the whole product. Modular improvements are significant as they can help introduce new technologies or functions into products and thus gain a competitive edge on competitors. Time would be saved, as only one module need be redesigned, which would be a competitive boon. Design for adaptability is an extension of this concept in that designs are made to be easily altered. This can be achieved with modularity and by increasing the independence of the modules. Each module can then allow for flexibility by not allowing constraints such as shape, size and interfacing to interfere with its function. Generic design is the next stage up, whereby each product is a further development of a previous one. Thus, a whole range of products would be based upon a single standard, or generic, design. Each product in the range would be based upon a combination of defined additions and subtractions from the generic design. This can be extended again into "generational design", where new generations of products can be based upon earlier ones. Again the savings in design and manufacturing time and cost allow the achievement of integration and hence time to market. Delta, Meem, Noon, Sheen and Jeem all made use of these concepts. Delta Machine Tool developed whole ranges of machine tools based upon a generic or standard design. This generic technique was also used by both agricultural machinery firms, Sheen and Jeem. Meem also used it and the modular concept. Each air conditioning machine in a range was typically a more powerful version than the ones below it, the only difference being the power rating of the electric motors and fan size. Each machine was made up of modules - fan, coolers, power unit and ducting. This was to both ease assembly and also ease servicing of their products. Meem also used generational design - basing new products on old ones. Noon Air Conditioning also used the modular concept. However, these concepts - modular, generic and generational design - were only used by the firms who were producing products in volume - the firms producing to contract (the railway brake and conveyor firms) did not use them.

8.4.6 Standardisation

Standardisation is another technique which improves integration. It was found that CAD had not led to an increase of the amount of standardisation of products. Rather, the degree of existing standardisation and management implementation of standards determined the amount. These two were influenced by the nature of the firms' products. The more amenable the product was to standardisation the more standards the firm would have. Similarly for the design structured interview firms high standardisation was determined by simple products, narrow product ranges, ageing product ranges and unchanging product technology. Second, management's consistent and continual attention to production considerations throughout the design process. It was this factor which determined that the company with a highly complex and wide product range (Meem Air Conditioning) had as high a standardisation as a company with a simple and unchanging product (Alef Pumps). Hence, both sets of case studies show, aside from firms with simple products, that management attention to increasing standardisation produced results. For example, the concern to minimise production time led Meem Air Conditioning to place an emphasis upon the utilisation of fewer components. This made assembly easier which led to fewer mistakes, both of which reduced assembly time.

8.4.7 Summary

The methodology solutions examined by the research (mapped in Figure 8-3) were up-fronting the design effort, product specification, use of methodologies - DFA, QFD, BS 5750, design freeze, modular, generic and generational design and standardisation. Green issues, recyclability and disposability of products have emerged, since the survey, as being prominent. This makes design more complex and challenging. It can be concluded that methodology solutions (DFA, QFD) had little use and impact in industry. It would not be fruitful to devote government support for firms to methodology solutions until the issue of non-adoption has been addressed. Academic research can undertake work to extend the methodologies available and to provide easily adopted methods. Second, management's approach to, and use of, methods for design freeze, generational design and standardisation was the key factor in producing better performance. In other words, management have to do these things and not just say they do them. This was most clearly seen in the case of standardisation where too little was done to improve standardisation within firms. If management prioritised design for manufacture they would have to devote more effort to increasing standardisation.

8.5 Technology Solutions

The technology solution domain describes the situation where the utilisation of a technology does away with, or bridges, the gap between the design and production functions. Technology, as investigated here, consists of 1) CAD, 2) advanced use of CAD, 3) CAD/CAM, 4) FMS and 5) data and information exchange. Each of these will be considered in turn. A major limitation of technology is that the structure of industry may prevent the technology bringing about the necessary (and desired) integration. This may be because, for instance, the CAD system would be implemented in the design department and production would be denied access to it. Even if production had access to the CAD system it would not follow that production could influence the design. There thus exist structural barriers which could prevent technology fully bridging the gap.

8.5.1 CAD

Delta Machine Tools had improved its design for assembly through CAD use by being more able to make design changes quickly. The ability to produce new versions of designs quickly had led to better design, as changes were easier to make and more rapid. Thus, the chain of design drawings from layout, detail to final assembly, and the improvement due to ease and rapidity of change, had led to fewer mistakes on the shopfloor. In fact the increased confidence that the firm had in its design methods had allowed it to scrap a machine design it was not satisfied with and start again as they thought they could do it better. Previously, they would never have thought of this because, on paper it would have taken too long. CAD had thus enabled the firm to shorten the time taken to design a new machine. This, however, was not solely due to CAD. CAD had only helped reduce the up-front time (design time before pre-production).

8.5.2 Advanced Use of CAD

An example of advanced use of CAD was Jeem Agricultural Machinery. They were making mechanical shovels which fitted on the back of farm tractors. These primarily consisted of a hydraulic arm. The kinematics of this arm were designed and simulated on their CAD system. This enabled them to check the functionality of the arm, ensure its safe working and reduce its weight, using finite element analysis.

8.5.3 CAD/CAM

Theta Railway Brake had excellent use of CAD/CAM. The degree of integration between the CAD and CAM was such that a few minutes after designing a new component it could be produced on the DNC machine downstairs. Due to the possession of the DNC machines the company had changed its business and design policy. Pneumatic interconnections for the brakes are problematic. If piping is used for the interconnections it is expensive both in design and in assembly time and labour. The company, therefore, replaced physically close interconnections with solid aluminium blocks (aluminium to save weight). Previously, these were sub-contracted out for manufacture using precision casting. The DNC machines had made it cost effective to machine solid blocks of aluminium into the correct shapes. The firm had thus made the business decision not to invest in precision casting equipment (aluminium can be a difficult metal to cast due to porosity and cavities). The solid blocks were also easier to design than piping layouts. More importantly, the direct link from CAD to CAM for the production of these blocks made it very cost effective. Therefore, in designing the pneumatics these block were used as much as possible (long interconnections still had to be made with pipe). This selective use of CAD/CAM was an essential element of the company achieving integration.

8.5.4 FMS

Again the effective use of FMS can aid the achievement of integration and time to market. Delta Machine Tool's use of FMS seven days a week had helped to shorten lead times. Theta Railway brake with CAD/CAM had also reduced lead time. However, FMS can only be used for limited "sets" of components and thus careful decisions have to be made on where to deploy it. Effective FMS also depends upon it being closely integrated with a CAD/CAM environment, as can be seen from the railway brake firm above. This was easier for Delta as they designed the very machine tools used in the cell. They could thus interconnect and integrate them easily. Theta Railway Brake had to employ consultants to set up their DNC cell and to write special software for it. An integrated CAD/CAM-FMS environment requires an enormous capital investment which must be properly assessed before being embarked upon.

A further problem with CAD/CAM and FMS is the one-way flow of information - from design down to production. This means that important information deriving from resolving the difficulties of manufacturing a component need to be relayed back to the designers, both to keep the design up to date and also for future reference. Theta Railway Brake had achieved this with a procedure. When the shopfloor operators made changes to the CNC programs, the changed programs were sent by the DNC back to the programmers and the engineering manager. The changes were then examined and, if appropriate, approval was given for their incorporation into the program for the part.

8.5.5 Data & Information Exchange

CAD is not much help in achieving integration and speeding design if every component developed on it is drawn from scratch. Hence, a common database of drawings and associated information - bills of material etc - is required. Here, the increasingly popular electronic data interchange (EDI) is emerging as important. Data can be transferred from one location in the company to another, or even between companies. This is a great help in integrating suppliers into the development process and reducing time to market. It does, of course, depend upon a standard for information interchange. The structured interview companies have found that the IGES standard is too limited (transferring geometric data but omitting dimensions and tolerances let alone CAM data). Companies have had to develop their own proprietary standards using consultants - as was the case with Theta Railway Brake. Smaller firms were content to exchange AutoCAD files.

8.5.6 Summary

The research showed that technology as a solution to the design - production interface is limited for three reasons - its diffusion, its use and technological limitations (shown in Figure 8-4). Although there is a reasonably high usage of computer-aided design in the mechanical engineering industry, some 60%, this is still not widespread enough for it to fully transform the interface. Goldhar et.al. (1990) say that "the diffusion of the technology is nowhere near the level expected a decade ago". Second there is the use of CAD, although CAD had the potential to improve large parts of the design process, in for example conceptual and functional design, CAD in the mechanical engineering industry is only used for drawing.

Fig 8-4 Technology Conclusions Map

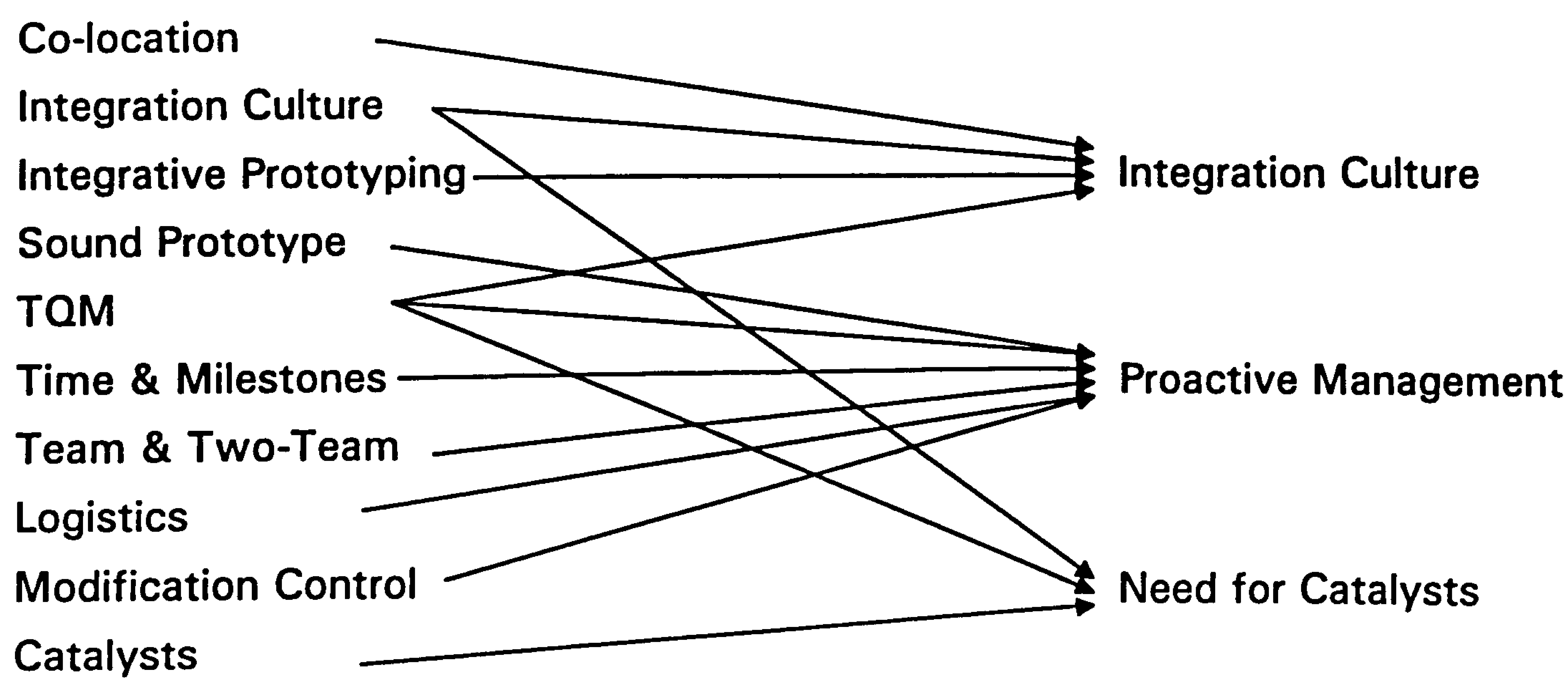
Further, the survey found that most firms are only using the 2D drawing ability of CAD and are not using its 3D capability (cf. Simmonds & Senker 1989). The more sophisticated uses of CAD, for design for assembly etc, were not taken up by firms. This means that the real gains of CAD - 3D design and simulating finished products and their assembly before anything is made - are not even approached by companies. Also, the more sophisticated benefits of CAD, particularly the potential to improve consideration of design for manufacture, were not realised. Thirdly, there are the technological limitations which were shown up by the case studies. The integrated use of CAD/CAM was only achieved by a small minority of firms, three of the case studies. Only 40% of firms using CAD also had CNC machines. This means that the integrative ability of CAD/CAM is restricted to roughly a quarter of the mechanical engineering industry. Thus, only a minority of firms are able to contemplate CAD/CAM integration, let alone achieve it. Second, this was only for a select range of their components and not for the whole product itself (eg. aluminium manifolds). Thus, the integrative ability of these technologies in practice, as used in industry is very limited. Filippini & Raffo (1990) confirm this: "it appears that most fully automated, computer-controlled manufacturing systems are restricted to a certain product "space", defined by technological and volumetric parameters". Some examples of this limitation from the literature are: the automated selection and optimisation of cutting tools to produce threads (Maropoulos et al, 1990); a sheet metal punching machine and attached CAD/CAM system (Webb et al, 1990); an automated generator of NC programs for rotational parts (Zhang & Mileham, 1991); a system for producing and rapid prototyping of microwave filters (similar to Theta & Upsilon's aluminium manifolds) with some manual assistance for CNC programming (Yu & Yule, 1993); and the design and production of disc cams (Su & Swannell, 1993). From the case studies only Delta and Theta were able, with the use of CAD/CAM and FMS cells, to achieve a high degree of integration between design and manufacture. FMS being a more complex and expensive technology can be assumed to be even less prevalent in industry. Hence, it can be concluded that the ability of CAD to integrate the design and production functions of companies was not developed.

The case studies showed that CAD had changed the balance between costs and benefits of design modifications - firms were more effectively able to modify designs when they possessed CAD. Both Delta and Upsilon had increased the number of times they could pass through the design loop thus perfecting the design before manufacture started. CAD allowed firms to correct manufacturing problems and respond to changing customer needs more efficiently - saving time and money. Therefore, the scope for CAD to improve firms' competitive position was limited to speeding and easing the drawing process and in some special circumstances to providing highly integrated CAD/CAM-FMS systems.

It was also seen from the case studies that the difference between the good and poor performing companies was due to their management of CAD and the design process. Companies such as Delta and Upsilon were better because of their management, CAD only being a prerequisite and not a determinant of their performance. To increase the competitive capability of CAD, three things need to be done by firms. First, management need to widen their focus from drawing onto the whole design process. Second, production engineering and manufacturing personnel need to be more involved in design, and particularly in using CAD. This needs to take place within a design - production integration framework. The necessity of which was shown by Upsilon Railway Brake, where CNC programmers given designs early gave them only superficial examination. With the presence of an integration culture (see the next section), in the case of Meem Air Conditioning, early consultation was very fruitful. Third, there needs to be better overall management of the product design process. Such as the implementation of management procedures, and mechanisms, such as design reviews. Only in this context will CAD produce competitive results.

The recession has curtailed investment in CAD, meaning that its potential is further weakened. This will result in a drop in demand and thus CAD supplier firms will reduce investment in R&D to enhance and improve the technical capability of systems. This will hamper the contribution of CAD and its associated technology for many years. There is thus the question of how the huge gap between integrated users of CAD/CAM and the majority can be bridged. Solutions external to the firm include support to enable firms to invest in CAD and further technological development of systems. It can be recommended that the government encourage CAD use, particularly on PCs, by funding a scheme to subside firms' purchase of PCs. Further, universities and CAD developers should engage in research to develop the technology, particularly CAD to CAM technology. Also research needs to be undertaken to extend the applicability of CAD/CAM from the 'easy areas' of die and tool machining, manifolds, sheet metal etc into non-traditional areas of assembly and especially total product design - designing and simulating the assembly of a complete product on the system. This should, as much as possible, be done in combination with real firms in order to overcome the teething problems experienced in the real environment. Only through the inclusion of user firms can the problems associated with transferring designs from CAD to CAM be resolved. However, it can be concluded that due to the limited diffusion, capability and sophisticated use of CAD/CAM and the current recession the main solutions to the design - production interface will have to come from elsewhere, that is organisation or management.

Fig 8-5 Organisation Conclusions Map



8.6 Organisation Solutions

Organisation, or management, refers to solutions which concern the organisation and management of the design - production interface. Externally it could refer to the organisation of industry, for example that firms should employ design consultants for product design. Also that designers and engineers are educated in organising and managing product design. Internally, it refers to how the design and production functions are organised and how the product design process is managed. It could consist of producing some guidelines for how the relationship between production and design should be organized. For instance by recommending that production engineers be included on product design committees, or that product project teams be set up which include production personnel. This solution approach is a very popular, recommended by: Oakley (1984), Bronikowski (1982), Whitney (1989) and Ettlie (1988).

The major limitation of organisation solutions is that there may be structural problems of industrial organisation that prevent the inclusion of production personnel in other organisational functional units. The highly specialised nature and structure of British industry did not appear from nowhere but developed to suit the interests of those it serves. Thus, functional boundaries may be a necessary part of the maintenance of this structure. Hence, attempts to do away with such boundaries may fail.

It has been seen that the two other solutions - methodology and technology - were limited. It was not the techniques themselves which helped achieve design - production integration but management's use of them, ie. management was the deciding factor. It is concluded, in general that it is management attitude and approach to managing the design - production interface that determines good performance. This was shown by the comparison of Theta and Upsilon Railway Brake. Upsilon, the leaner and fitter company, was the better performer. This was due to the attitude and approach of its management. They were not complacent about design and production integration, they paid more attention to integration and held more co-ordination meetings. Coming to specifics there is a need for management techniques and methods that improve product design and manufacture, particularly integrating them; that reduce time to market and that help companies achieve competitive edge. The theoretical options, as identified in Table 8-1, are project teams, matrix organisation, product champion, project management, simultaneous engineering, two-team, co-location, Liaison officer, ad-hoc consultation, and TQM. Co-location and ad-hoc consultation are the minimum that companies can do to improve integration between design and production. To be better than the rest more than this minimum must be done. The survey showed that matrix organisation was hardly used at all, therefore, it can be excluded from further consideration (it also has high overhead costs and thus not worth recommending for adoption). Meetings and simultaneous engineering were the most frequent co-ordination mechanisms found by the survey. The case studies showed that the key management factors were an integration culture: co-location, integrative prototyping, developing a sound prototype; TQM and modification control; team and two-team; time & logistics; and catalysts, including simultaneous engineering. Each of these, shown in Figure 8-5, is discussed below.

8.6.1 Integration Culture

Three of the case studies (Alef, Meem and Sheen) show that possessing an integration culture was the key to their better performance. Alef Pumps placed a much more consistent, wider, and longer consideration of design and production than Beh. This attitude and approach enabled them to have a better overall performance. Senior management must also be committed to the integration philosophy and team-working. They must give their backing to the project and allow team members the time to work in the team. This was illustrated in the case of Sheen Agricultural Machinery where the previous founder managing director did not allow design engineers onto the shop floor. This design-led approach had resulted in the company's latest machine being 50% over cost. The newly appointed managing director had pursued an extremely proactive approach - encouraging and chairing meetings etc - to get the design and production personnel to talk to one another and overcome their former non-integrative approach. This took the form of regular design review meetings and also encouraging informal consultation between engineers. He was an excellent manager of people. He was able to instil a team spirit within people who previously had been under orders not to talk to each other. He had emphasised the co-operative and common tasks of the team to the members above their own specialist niggles and complaints. This approach had proved very successful and the new machine was a much more integrated design. Again in the case of Meem Air Conditioning the pervading of the organisation with an integrative culture had produced results. However, for them it was not just a question of a culture of co-operation but of managing it. They did this through the use of TQM, design review meetings, milestones, modification control and by the use of integrative prototyping, discussed below.

Co-location is a technique for improving design and manufacturing integration. Locating the design and manufacturing engineering personnel in the same office helps informal consultation. This leads to problems being resolved earlier than otherwise and more quickly. Many companies have found co-location to improve relations between the two sets of engineers and thus improve time to market. Delta Machine Tools had reorganised its whole engineering department to place the design and production engineers in one open plan office. This had greatly improved the informal communication between the engineers and resulted in improved designs being produced. The counter balance to this was the disciplinary attachments of the engineers concerned which, despite the physical proximity, still prevented engineers talking to one another. Co-location has the greatest advantage that it is cheap, requiring no extra staff or investment. It is particularly cost effective where a company has low staff numbers.

It was concluded from the survey that the prototype phase was the key phase of the design process. The case studies also demonstrated the importance of this phase. Prototyping has been the traditional way in which the concepts of a design and its manufacture are tested. Normally, however, prototypes are made in special development labs away from the factory floor. This has one major drawback - those who will eventually make the production units have not made the prototype and thus their experience and skills are not included in the design before it is manufactured. Meem Air Conditioning had changed its prototype development policy to one of integrative prototyping. Previously, prototypes were built in a specialised development department. This department had been disbanded in favour of building prototypes on the shopfloor. Thus, the fitters responsible for ultimately building a machine would actually build the prototype. The project engineers would visit and consult with the shopfloor as the prototype was being built. They would then make changes to accommodate ease of build, ease of access, ease of maintenance, and ease of component replacement for service etc. The pressure of competition meant that price was very sensitive and this meant that production time had to be minimised - by ensuring components were easy to assemble and that the best way to assemble them was used. As the project engineers do not spend all of their time on the shopfloor they do not know the best way to make something and thus it was necessary for them to consult with the shopfloor on this issue. This approach to prototyping can be extremely valuable in achieving integration.

The other aspect of prototyping was to produce a sound prototype and not skimp or scrimp on it. This was illustrated by Delta Machine Tools. Delta made effective use of the prototype stage to ensure that the resulting design was efficient to manufacture. They went through the design loop as many times as necessary until they were satisfied with the manufacturability of the design. This approach was starkly illustrated by the two railway brake firms. Upsilon also made effective use of the prototype stage and went through the design loop several times. Theta, on the other hand, skimped on the prototype stage and even engaged in premature manufacture - which resulted in many modifications having to be made. This skimping was for two reasons, 1) scrimping - they said they did not have the money and 2) skimping on time due to the delivery pressures from customers. It is obvious that if they spent more time and money on "perfecting" the prototype they would spend less time and money on correcting problems and thus be able to meet customer deadlines. Hence, the reason they were a poor performer was because they lacked the management control of their projects. Once, they had their project management sorted out and made the investment in prototypes their performance would improve. One way to do this would be through the use of TQM (dealt with next) or project management proper. Either way they needed a catalyst to provoke them from their current complacency and lack-lustre performance.

8.6.2 Total Quality Management

TQM was placed in the organisation solution group as it requires more organisational adaptation than QFD and can act as a catalyst drawing together the disparate parts of an organisation and focussing them on the tailoring of products for manufacture (this happened in the case of Meem Air Conditioning). TQM makes the down stream function the customer of the upstream one. Thus, the next stage down stream in the process, for example manufacturing, is the customer of the upstream function, design. A chain of customers is thus set up, each of whom define the quality standards to be reached. Once standards have been set each unit of the organisation strives to continually improve upon them. Meem Air Conditioning employed the use of TQM. In this company, TQM had been the catalyst for increasing inter-departmental communication, both formal (paperwork) and informal consultation. They had adopted a philosophy of continual improvement. This had helped to reduce the barriers between departments and increase interaction with the aim of improving and speeding product design. The company placed an emphasis upon informal design - shopfloor co-ordination in order to ensure ease of manufacture. The philosophy was to engage in as much interaction as possible until things were running smoothly. Thus a project engineer would hold informal consultative meetings with colleagues to approve, and advise upon, designs and would also visit the shopfloor to show drawings in progress and to obtain advice. This interaction with the shopfloor would continue during prototype construction and production. TQM had been catalytic in organising this process.

Once products are in production they can still give rise to design changes. For example, Meem Air Conditioning had a relatively high rate of modification, 11-20% of components. In order to control these changes and their impact the company operated a procedure to control changes. Production modifications would be originated by shopfloor personnel filling in a change proposal form. This was sent to the engineering manager for approval. The quality manager had to give approval too. Questions would be asked as to which unit the modification affected and how many. A checklist was used to consider the effect a modification would have. After approval the standards manager would issue drawings to all parties concerned: stores, purchasing, spares, sales etc. This issue of drawings was controlled in order to ensure that the most up to date information was used. An information bulletin informing distributors and customers was also periodically issued. Engineering changes would arise from suppliers changing component sizes and other sources - eg. product improvement. Independent of the source of the change, major modifications would be introduced immediately, others would be prioritised and rolled-up for introduction. Strenuous attempts were made during the prototype stage to eliminate modifications in order that they were minimised during the changeover to manufacture. All of these efforts had enabled the company to reduce its modifications from previous years.

8.6.3 Team & Two-Team

The survey showed that meetings followed by project teams were the most frequent design - production co-ordination mechanisms. Teams were used in various forms by the structured interview firms. It was concluded from the case studies that it was important to separate the strategic and operational elements of the team. This can be done by adopting the Two-Team approach. The first, or strategic, team was convened to consider the strategic issues of product design. It would be responsible for setting and controlling budgets and setting time-scales. It would also review the progress of designs currently in development and correlate this with marketing. This team would consist of senior managers of the relevant functional areas, including company directors in some cases. The second, operational or tactical, team was charged with the day-to-day management of the process of the introduction of a new product. It would thus be concerned literally with the nuts and bolts of the design and development. The team would typically consist of design and production engineering personnel plus factory representatives. It would consider the manufacturing problems of the design and how to resolve them. The strategic team would also have to take responsibility for forming the operational team, maintaining its dynamic and disbanding it at the end of the project. For the next project a new team should be assembled from different personnel, to provide an element of challenge and prevent team members from becoming complacent.

This two-track approach to the management of the introduction of new products was found to be more successful for the companies using it than for firms not using the approach. Thus, on strategic teams, Delta Machine Tools had a project team headed by a project manager. Regular meetings were held between the various project managers to discuss strategic issues, something which entailed quite a bit of politicking. Theta, the poorer performing railway brake firm although possessing project teams did not hold these regular strategic meetings. Alef Pumps held monthly meetings of a project policy committee which considered progress on all the companies contracts. Jeem Agricultural Machinery had product committees for each of its two product groups. These looked at market trends, and production opportunities and costs. Sheen also had regular product review meetings which dealt with strategic issues, the market and technical performance of machines in production, progress of machines in design and considered major decisions. Meem also held regular product review meetings attended by senior managers which reviewed progress and set deadlines. Hence, these firms demonstrated their commitment to good practice by using these strategic teams. Similarly companies had second level teams. Delta held regular design - manufacturing review meetings. Jeem's project engineer had an informal team of three people who were responsible for design - production liaison. Sheen had a project team and every couple of months held design - shopfloor review meetings. Upsilon held regular design - production review meetings. Delta, Upsilon, Jeem and Sheen all had this two-team configuration. The exceptions were the smaller companies - Alpha (tactical team), Beta (strategic only), Alef (strategic), Beh (tactical), and Meem (strategic). The companies with strategic teams did not have formal second teams - co-ordination was left to informal consultation. Those with tactical teams had them consider the strategic issues - this was because they were small companies. The exception was Meem who, although being a large company, only had a strategic team. They were able to get away with this due to their integration culture discussed above. It can be concluded that this two-team approach to the management of the introduction of new products was very useful. It helped to separate and concentrate companies' attention on the key issues - deadlines and progress at the strategic level and design - production liaison at the tactical level. This meant engineers could get on with their jobs but would be kept in check and on schedule by the strategic team. The approach helped to improve the management of design - production integration, and produced better performing companies.

8.6.4 Time & Logistics

Managing time is, of course, the fulcrum of introducing new products on time. Upsilon Railway Brake used milestones in default of regular design - production meetings: at the beginning of a contract, when the major detail drawings had been done and when production want or are pressured for manufacture. This lapsing of regular meetings, which was put down to a lack of staff, is not ideal. It does illustrate how milestones can be used as an extra control mechanism on top of regular meetings, particularly if senior staff are involved in them. Jeem Agricultural Machinery had milestones at project definition, after detail drawing and costing completion and after prototype testing. The project engineer held meetings at each of these milestones, but production engineering were only included in the final meeting. Meem Air Conditioning used milestones as one way of managing time. The project leader of the project team would hold meetings at the milestones of: before and after prototype construction, and before and after production machines were produced. The first production meeting may, or may not, be held depending upon the outcome of the second prototype meeting. Six months after product introduction another milestone meeting was held to check that everything was ok. For each project a project review meeting would be held monthly, six weekly or more often as necessary. These meetings would review progress and set deadlines. These targets may be unattainable, but will concentrate the minds of the team on what they are trying to do.

Logistics are an important part of the integration equation. The capability to manage ones internal operations (design and manufacturing) and external operations (sub-contractors) is crucial for achieving time to market. This capability is illustrated by Delta Machine Tools. They had successfully fended off competition from the Japanese and Koreans by shifting their operations to "buy-in-parts" rather than manufacture them in house. Their latest machine only had 73 in house manufactured parts, the rest were bought-out. They had reduced the lead times on the last three new machines they had introduced. The improvement had come about due to three factors. First, basing new designs on current machines, thus producing families of machines. The first machine so introduced was completed in seven months. The company had never done a new design so fast. A further two machines were also introduced in a similar time. The second factor was the project team management. The third factor was organising suppliers and internal manufacture to deliver parts when needed, and quicker than before. It was this logistics capability of the firm that had been key to its competitive edge.

8.6.5 Catalysts

As was seen from Meem Air Conditioning the use of TQM acted as a catalyst for increasing inter-departmental communication, both formal and informal consultation. Similarly, the newly appointed managing director of Sheen Agricultural Machinery pursued an extremely proactive approach. He had encouraged and chaired meetings - to get the design and production personnel to talk to one another and overcome their former non-integrative approach. His intervention, which had been brought about by the financial difficulties of the firm, acted as a catalyst in bringing people together. Thus, these catalysts had been important in removing a previously complacent attitude towards design - production integration and replacing it with a process and culture of co-operation.

Simultaneous engineering, or concurrent engineering, is another technique for achieving design - production integration which has catalytic effects. The survey showed that it was the equal most popular method of organising design - production relations. It has been seen that several of the structured interview companies had developed complacent attitudes and management practices towards product design. In order to improve their performance something has to be done. Either, as in the case of Sheen, a financial calamity occurs which requires rectification via radical restructuring (ousting of the founder MD and importing a new one), or the current management adopt a technique which brings about transformation without ructions at top management level. Both of these alternatives need to bring about the change below top management level or else they are failures. It has been seen that TQM has been able to fulfil this catalyst role. It has stirred up (but not shaken) top management and line employees. However, recently the TQM bandwagon has been running out of steam (Atkinson 1993; Childe et al, 1993). Further, TQM is a whole company approach and does not specifically address itself to product design. Simultaneous engineering, on the other hand, deals specifically with design - with both product and process design - and only these issues. It is not a total organisation gobbler like TQM. Simultaneous engineering is a recent import from America (where it is known as concurrent engineering). It is a powerful technique for improving new product introduction. It was for this reason that work was carried out on it by the author. This work has considered the strategic choice of simultaneous engineering (Riedel & Pawar, 1991), its tools, techniques and technology (Riedel & Pawar, 1993a), its management for achieving integration (Pawar & Riedel, 1993), achieving time to market (Pawar et al, 1994) and strategies for implementation (Riedel & Pawar, 1994). This work will be extended and developed so that a practical version of simultaneous engineering can be evolved, through industrial collaboration. This research would have a number of dimensions: implementation, managing, progressing, team and barriers. Research into implementation of simultaneous engineering would consider the problems and their solution for adopting simultaneous engineering by companies new to it. How it can be adjusted to specific company contexts, how it can be easily adopted and absorbed by companies, the role of pilot projects, the role of the steering committee, strategic vision and how to extend its adoption throughout companies. Research into managing simultaneous engineering would investigate how to manage simultaneous engineering once adopted. It should consider issues such as managing the varying intensity of simultaneous engineering (a what to do when type approach), communication and co-ordination between design and production, the use of CAD and the strategic dimension of which products to apply it to. Research into progressing would consider how to improve one's simultaneous engineering performance, particularly over many product launches - to reduce the time and effort involved and increase competitive edge. Research into team would consider the team, its selection, management, motivation, when to form and disband them, the use of strategic and operational teams, and the politicking that is an inevitable part of the strategic team. Research into barriers would examine what the barriers to simultaneous engineering adoption are and how they might be overcome. Some of these issues will be taken up by the author in his future research and also by others.

8.6.6 Summary

The organisation solutions section has presented the conclusions relating to the management of the design process. It was found that the better performing companies all had elements of the following in place: co-location, an integration culture, integrative prototyping and development of a sound prototype, TQM, project management, time & targets, two-team, logistics, modification control, and catalysts. The complacency of firms was jolted by catalysts - TQM, commercial flops and the recession. It is concluded that firms will only improve their design - production integration when forced to by one of these catalysts. The most appropriate catalyst for this, simultaneous engineering, was not investigated by the case studies. This was because, as with green issues, its importance emerged after the research study had been designed. It is recommended that companies wishing to improve their design - production integration and achieve competitive edge adopt simultaneous engineering. Simultaneous engineering will be further investigated by the author.

8.7 Conclusion Summary

The conclusion of the study of the design - production interface in the UK mechanical engineering industry divided the solution approaches to the problem of the interface into three: methodology, technology and organisation solutions. The key findings from the survey and case studies were used to draw conclusions and recommendations for each of these solution approaches. The methodology solutions discussed were up-fronting the design effort, product specification, use of methodologies - DFA, QFD, BS 5750, design freeze, modular, generic and generational design and standardisation. It can be concluded that methodology solutions (DFA, QFD, BS 5750) had little use and impact in industry. It would not be fruitful to devote government support for firms to methodology solutions until the issue of non-adoption has been addressed. Academic research can undertake work to extend the methodologies available and to provide easily adopted methods. Second, management's approach to, and use of, methods for design freeze, generational design and standardisation was the key factor in producing better performance.

The research showed that technology as a solution to the design - production interface is limited for three reasons - its diffusion, its use and technological limitations. There is a reasonably high usage of computer-aided design in the mechanical engineering industry, some 60%, but this is still not widespread enough for it to fully transform the interface. Second, there is the way CAD is used. Although CAD had the potential to improve large parts of the design process, in for example conceptual and functional design, CAD in the mechanical engineering industry is only used for drawing. Further, most firms are only using the 2D drawing ability of CAD and are not using its 3D capability. The more sophisticated uses of CAD, for design for assembly etc, were not taken up by firms. This means that the real gains of CAD - 3D design and simulating finished products and their assembly before anything is made - are not even approached by companies. Thirdly, there are the technological limitations which were shown up by the case studies. Only Delta and Theta were able, with the use of CAD/CAM and FMS cells, to achieve a high degree of integration between design and manufacture. The survey found that only 40% of firms using CAD also had CNC machines. This means that the integrative ability of CAD/CAM is restricted to roughly a quarter of the mechanical engineering industry. FMS being a more complex and expensive technology can be assumed to be even less prevalent in industry. Hence, only a minority of firms are able to contemplate CAD/CAM integration, let alone achieve it. Further, this was only for a select range of their components and not for the whole product itself (eg. aluminium manifolds). Hence, it can be concluded that the integrative ability of these technologies in practice as used in industry is very limited.

It was also seen from the case studies that the difference between the good and poor performing companies was due to their management of CAD and the design process. Companies such as Delta and Upsilon were better because of their management, CAD only being a prerequisite and not a determinant of their performance. To increase the competitive capability of CAD, three things need to be done by firms. First, management need to widen their focus from drawing onto the whole design process. Second, production engineering and manufacturing personnel need to be more involved in design, and particularly in using CAD. Third, there needs to be better overall management of the product design process. Only in this context will CAD produce competitive results. The recession has put paid to investment into CAD, meaning its potential is further weakened.

It was shown for the methodology and technology domains that the better performing companies not only used certain techniques and technologies but used them better. This was because their managements paid more attention to integrating the design - production interface. It was concluded that management was the deciding factor. The management approaches which could be adopted were discussed in the organisation solution domain. These were co-location, an integration culture, integrative prototyping and development of a sound prototype, TQM, project management, time & targets, two-team, logistics, modification control, and catalysts. It was found that the better performing companies all had elements of these in place. The complacency of firms was jolted by catalysts - TQM, commercial flops, competitive pressures and the recession. It is concluded that firms will only improve their design - production integration when forced to by one of these catalysts. The most appropriate catalyst for this, simultaneous engineering, was not investigated by the case studies. This was because, as with green issues, its importance emerged after the research study had been designed. It is recommended that companies wishing to improve their design - production integration and achieve competitive edge adopt simultaneous engineering.

8.8 Further Research - Simultaneous Engineering

This section discusses the research issues requiring further investigation in the light of the conclusion that simultaneous engineering is the way forward. Research would need to consider a number of dimensions: strategy, implementation, barriers, tools & techniques, organisation structure, managing, team, and performance/evaluation.

The first question is that of strategy. Companies will be adopting simultaneous engineering because they wish to improve their competitive position, and preferably to gain a competitive edge over their competitors. This aim necessarily has strategic dimensions and implications and requires a strategic vision of where one is going, how and why. The first implication is that top management must adopt a simultaneous engineering strategy which defines the goals of the implementation and sets out a programme. This would include, for instance, written statements of the goal of a certain market share to achieve within a set time period, or to achieve a competitive lead within a time period (and thence maintain it). It would also set out a programme for simultaneous engineering: which products and divisions of the company to apply it to, an outline of how it is to be applied and the details of monitoring the programme. Having adopted a programme Starkey & Mckinlay (1993) show that top management must be committed to simultaneous engineering for it to be successful. Thus the factors which gain, ensure and hinder top management commitment should be investigated. Does the appointment of a simultaneous engineering champion more effectively secure and ensure top management commitment than a steering committee?

Research into implementation of simultaneous engineering would consider the problems and solutions for adopting simultaneous engineering by companies new to it. What type of implementation strategy should be pursued - top down, bottom up or gradual incrementalism (Riedel & Pawar 1994, Starkey & Mckinlay 1993). How can simultaneous engineering be adjusted to specific company contexts, how can it be easily adopted and absorbed by companies. The role of pilot projects in implementing simultaneous engineering, the role of the steering committee, and strategic vision. Also having successfully implemented a pilot project, or one-off implementation, how can this be extended to the rest of the company. What mechanisms and personnel are key in diffusing simultaneous engineering adoption throughout the company? Research into barriers would examine what the barriers to simultaneous engineering adoption are and how they might be overcome.

Research into managing simultaneous engineering would investigate how to manage simultaneous engineering once adopted. It should consider issues such as managing the varying intensity of simultaneous engineering (a what to do when type approach), communication and co-ordination between design and production, the use of CAD and the strategic dimension of which products to apply it to. It would also consider the training needs of the various personnel involved. Further, research needs to look at the important related issues of communication - what is to be communicated and when - and coordination - what mechanisms are best in which situations and who should be involved. It would need to investigate the types of organisation structure which best suit certain situations. The starting point here would be Clark & Fujimoto's (1991) analysis which starts with lightweight team managers, through heavyweight team managers to full matrix organisation. Which of these strucyures is best in which company context?

Research into team would consider Team Orchard - that is, the team, its selection, management, when to form and disband teams, and the use of Two-Team: strategic and operational teams. The concept of team orchard expresses the idea of a manager being in charge of an orchard of potential team members. It is the managers job to select, nurture, develop, heal, prune (reel in/ attenuate their discipline specific tendencies), and cross-breed (mix) team members to form successful teams for each project. Different projects would require different teams, with different biases in their team member skills and abilities. The management of the team and its performance is the responsibility of the manager - who should form and disband teams as and when they are needed, monitor their performance and intervene where necessary to redirect or refocus their attention upon their task. Research would also consider team motivation, training and the politicking that is an inevitable part of the strategic team.

Research into progressing would consider how to improve one's simultaneous engineering performance, particularly over many product launches - to reduce the time and effort involved and increase competitive edge. In order to do this some form of performance measure or evaluation framework needs to be developed. This would enable companies to assess their performance during a simultaneous engineering implementation and tweak or adjust their implementation to gain better performance. It would also allow each implementation to be compared with each other so that improvements over successive implementations could be monitored.

Some of these issues will be taken up by the author in his future research and also by others.

8.9 Recommendations for Companies

This section presents the recommendations for companies derived from the research, which can be adopted by them to improve their product design performance. The first recommendation to companies is for them to strictly adopt the policy of writing written product specifications for their products. The survey showed that not all companies did this and yet the interviews showed that increasing up front effort was crucial. Second, companies should increase the amount of consultation with production engineering and relevant production personnel during the drawing up of the specification. Third, companies should strive to increase the amount of standardisation in their designs. Perhaps even special initiatives should be mounted using a project team charged with the task of increasing the number of standard components used in designs.

It was concluded that CAD was a prerequisite for competitive strength, not its determinant. Therefore, it is recommended that companies should devote effort to improving their use and management of CAD. Efforts to improve the amount of standardisation of components using CAD should be made. The interviews showed that companies did not put enough effort into using standard components on their CAD system, nor in using CAD to increase the number of standard components. Management need to widen their focus from drawing onto the whole design process. They can do this by encouraging the use of CAD throughout the design process - encouraging initial CAD sketches to be shown to engineers further downstream, and getting them to comment on and adjust the design. Efforts to bring production influence, production engineering and manufacturing personnel input into the CAD drawing stage should be made, as these were lacking.

The principal recommendation as regards management is for the adoption by companies of an integration culture. This would mean the companies adopting an active management approach to integrating design and production functions within their company and adopting suitable mechanisms to achieve this - teams, meetings, TQM or simultaneous engineering - for instance. It is recommended that companies locate their design and production engineering staff in the same office as a step on this road. Another technique would be the adoption of integrative prototyping - the assembly of prototypes upon the shopfloor using shopfloor fitters etc. This would help to ensure the development of a sound prototype that had had production difficulties ironed out.

It is recommended that companies set up procedures for monitoring and controlling modifications of a design. These need to be explicit to help focus designers' and engineers' attention on the problem of getting a suitable design out of the door rather than limitlessly perfecting a design and releasing it late. Getting a design onto the shopfloor early also helps to identify and iron out production problems which can be adjusted in subsequent modifications of the design. This would greatly aid speeding the design process. Also it is recommended that management set milestones, with milestone meetings. This would emphasise the importance of time to the design effort and to allow progress, or the lack of it, to be identified and corrected, or improved upon, as appropriate.

It is recommended that companies actually do something about their product design process rather than remaining complacent about their existing performance. The research showed that when a catalyst was introduced into the company - a commercial failure, new managing director, TQM or simultaneous engineering - it led to the improvement of product design. Rather than waiting for the dull compulsion of a commercial failure or slipping market share, companies can do something now to leap ahead of the competition. They can implement a proactive program for the improvement of their product design performance. The type of program to be chosen would have to be assessed and one selected which was appropriate for the company as a whole. For instance, the research showed that simultaneous engineering was the best catalyst for improving product design, however, the company may wish to implement a TQM program to improve quality and performance overall. In this latter case the company-wide TQM program could be adapted specifically for the design and production functions to tailor it for the improvement of product design. In this product design improvement could go hand-in-hand with a company wide strategy for achieving competitive edge.

This concludes the doctoral thesis on the design - production interface in the U.K. mechanical engineering industry. I hope you found some benefit from reading it.

BIBLIOGRAPHY

Adler, PS; Riggs, HE & Wheelwright, SC. (1989) Product Development Know-How: Trading Tactics for Strategy. Sloan Management Review 31 (1) pp7-17.

Allen, D. (1993) Developing Successful New Products. A Guide to Product Planning FT/Pitman, London.

Archer, LB. (1974) Design Awareness & Planned Creativity in Industry Design Council, London.

Arif Bin Zainal Abidin, K. (1992) The Strategy for the Implementation of Concurrent Engineering MSc Dissertation, Department of Manufacturing Engineering and Operations Management, Nottingham University, Nottingham.

Arnold, E & Senker, P. (1982) Designing the Future. The Implications of CAD Interactive Graphics for Employment and Skills in the British Engineering Industry Occasional Paper No.9, Engineering Industry Training Board: Watford.

Atkinson, PE. (1993) How to Avoid TQ Failure Management Services 37 (12) December, pp 22-24.

Bartho, T. (1990-1991) The Nine Roles of CAD Management CAD User 3 (3-12) April - December 1990 & 4 (1-3) January - March 1991.

Bennett, DJ; Lewis, C & Oakley, M. (1988) Operations Management Philip Allan, Oxford.

Bernus, P. (1989) No Consensus Exists in Debate on Theory of Design Computer-aided Design 21 (9), November.

Bessant, CB. (1986) Computer Aided Design & Manufacture 3rd Edition, Ellis Horwood, Chichester.

Bessant, JR. (1979) Preparing for Design Studies: Ways of Watching. Notes Towards Appropriate Methodology for Studying Functional Specialists Design Studies 1 (2) October, pp 77-83.

Black, CD & Baker, MJ. (1987) Success Through Design Design Studies 8 (4) October, pp 207-216.

Black, I & Shaw, WN. (1991) Organizational and Managerial Aspects of CAD in Mechanical Design Design Studies 12 (2) April, pp 96-101.

Blackburn, P; Coombs, R & Green, K. (1985) Technology, Economic Growth and the Labour Process Macmillan, Basingstoke.

Boothroyd, G & Dewhurst, P. (1983) Design for Assembly - A Designers Handbook Technical Report, Department of Mechanical Engineering, University of Massachusetts.

Bosworth, DL; Jacobs, C & Lewis, JA (1990) New Technology, Shared Facilities and the Innovatory Firm Avebury, Aldershot.

Bower, JL & Hout, TM. (1988) Fast-Cycle Capability for Competitive Power Harvard Business Review 66 (6) Nov-Dec pp 110-118.

Brindley, K. (1990) Newnes Electronics Assembly Handbook, Techniques, Standards & Quality Assurance Heinemann Newnes, Oxford.

Bronikowski, RJ. (1985) Managing the Engineering Design Function Van Nostrand Reinhold, New York.

Bucciarelli, LL. (1988) An Ethnographic Perspective on Engineering Design Design Studies 9 (3) pp 159-168.

Burcher, PG. (1992) Effective Capacity Planning Management Services October 1992, 36 (10), pp 22-25.

Campbell, A & Warner, M. (1988) Organization for New Forms of Manufacturing Operations Management Studies Research Paper No 2/88 Department of Engineering, Cambridge University.

Carter, DE & Baker, BS. (1992) CE. Concurrent Engineering. The Product Development Environment for the 1990s Addison Wesley, Reading MA.

Charney, C. (1991) Time to Market. Reducing Product Lead Time Society of Manufacturing Engineers, Dearborn, Michigan.

Childe, S; Bennett, J & Maull, R. (1993) Manufacturing Re-engineering Around Business Processes In: Hassard, JS; Forrester, PL; Hawksley, C & Tang, NKH. (Eds) International Conference on Managing Integrated Manufacturing. Organization, Strategy & Technology 22-24 September 1993, (Keele University: Keele) pp 81-90.

Clark, KB & Fujimoto, T. (1991) Product Development Performance. Strategy, Organization & Management in the World Auto Industry Harvard Business School Press, Boston.

Clark, J; McLoughlin, I; Rose, H; and King, R. (1988) The Process of Technological Change: New Technology & Social Choice in the Workplace Cambridge University Press, Cambridge.

Commission of European Communities & Degimbe, J (Ed) (1986) Social Europe. New Technology & Social Change - Manufacturing Automation Supplement 1/86, Directorate General for Employment, Social Affairs and Education, Luxembourg.

Coombs, CF Jr. (Ed) (1990) Fabrication. Printed Circuits Workbook Series Volume 2, McGraw-Hill, New York.

Cooper, RG & Kleinschmidt, EJ. (1988) Resource Allocation in the New Product Process Industrial Marketing Management 17, pp 249-262.

Cox, J & Kriegbaum, H. (1989) Innovation and Industrial Strength in the UK, West Germany, United States and Japan Policy Studies Institute, London.

Cross, JD & Black, I. (1988) Putting the Design into Mechanical CAD: A Company Methodology, Design Studies 9 (4) pp 214-218.

Currie, CG; Mileham, AR; Miles, AW & Bradford, DT. (1990) "Cost Estimation at the Conceptual Stage of Design" In: Carrie, AS & Simpson, FI. (Eds) Advances in Manufacturing Technology V: Proceedings of the Sixth National Conference on Production Research 5-7th September 1990 (Strathclyde University: Glasgow).

Department of Trade & Industry. (1989) Design to Win. A Chief Executive's Handbook Prepared by the Design Council for the Department of Trade & Industry, London.

Department of Trade & Industry. (1991a) Profits by Design: A Summary of the Findings of an Investigation into the Commercial Returns of Investing in Design Prepared by the Design Council for the Department of Trade & Industry, London.

Department of Trade & Industry. (1991b) Managing the Financial Aspects of Product Design & Development. A Management Overview Prepared by the Design Council and 3i Enterprise Support Ltd for the Department of Trade & Industry, London.

Ettlie, JE. (1988) Taking Charge of Manufacturing. How Companies are Combining Technology & Organisational Innovations to Compete Successfully Jossey Bass, San Francisco.

Ettlie, JE & Stoll, HW. (1990) Managing the Design - Manufacturing Process McGraw Hill, New York.

Ettlie, JE & Warner, MD. (1992) "Good News and Bad News on US Product Development Practices" International Product Development Management Conference on New Approaches to Development and Engineering, Brussels, 18-19th May 1992, European Institute for Advanced Studies in Management, Brussels, pp 159-173.

Farr, M. (1973) Control Systems for Industrial Design Gower, Epping, Essex.

Filippini, R & Raffo, JF. (1990) Information Technology & Automation in Manufacturing & their Impact on Corporate Strategy In: Voss, C (Ed) Manufacturing Strategy - Theory & Practice. Proceedings of the 5th International Conference of the Operations Management Association, University of Warwick, 26-27 June 1990, (MCB University Press) pp 143-154.

Finger, S & Dixon, JR. (1989) A Review of Research in Mechanical Engineering Design. Part I: Descriptive, prescriptive, and computer-based models of design processes Research in Engineering Design 1 (1) pp 51-67.

Finger, S & Dixon, JR. (1989) A Review of Research in Mechanical Engineering Design. Part II: Representations, Analysis, and Design for the Life Cycle Research in Engineering Design 1 (2) pp 121-137.

Flurscheim, C (1977) Engineering Design Interfaces. A Management Philosophy Design Council, London.

Fowler, FS. (1988) Survey Research Methods Sage, London.

Francis, A. (1986) New Technology at Work Clarendon Press, Oxford.

Francis, A & Winstanley, D. (1988) Shaping Up for Design, CADCAM International, January.

French, MJ. (1988) Invention & Evolution. Design in Nature & Engineering Cambridge University Press, Cambridge.

Galbraith, JR. (1973) Designing Complex Organisations Addison-Wesley, California.

Galliers, RD; Merali, Y & Spearing, L. (1993) Coping with Information Technology? How British Executives Perceive the Key Information Systems Management Issues in the mid-1990s Research Paper No. 99, Warwick Business School, University of Warwick, Coventry.

Gasparski, W. (1989) Design Methodology: A Personal Statement, In: Durbin, PT. (Ed) Philosophy of Technology: Practical Historical and Other Dimensions Kluwer Academic, Dordrecht.

Gasson, P. (1974) Theory of Design Batsford, London.

Goldhar, JD; Jelinek, M & Schlie, TW. (1990) Flexibility & Competitive Advantage - Manufacturing Becomes a Service Business In: Voss, C (Ed) Manufacturing Strategy - Theory & Practice. Proceedings of the 5th International Conference of the Operations Management Association, University of Warwick, 26-27 June 1990, (MCB University Press) pp 176-213.

Gomory, RE & Schmitt, RW. (1988) Step-By-Step Innovation Across the Board Nov. p52-56.

Grewin, DE & Kolodny, H. (1992) Management of Advanced Manufacturing Technology. Strategy. Organisation & Innovation Wiley, New York.

Hanson, P & Voss, C. (1993) Made in Britain. The True State of Britain's Manufacturing Industry IBM Consulting Group/ London Business School, London.

Hart, SJ; Service, LM & Baker, MJ. (1989) Design Orientation & Market Success Design Studies 10 (2) pp 103-111.

Hartley, J. (1986) Fighting the Recession in Manufacture IFS Publications, Bedford.

Hartley, J & Mortimer, J. (1991) Simultaneous Engineering. The Management Guide 2nd Edition, Industrial Newsletters, Dunstable.

Hawkes, B. (1988) The CADCAM Process Pitman, London.

Hawkes, B & Abinett, R. (1984) The Engineering Design Process Pitman, London.

Hayes, RH & Wheelwright, SC. (1984) Restoring our Competitive Edge. Competing Through Manufacturing Wiley, New York.

Hein, L; Andreasen, MM & Olsson, F. (1984) Integrated Product Development In: Langdon, R. (Ed) (1984) Design Policy: Design & Industry Design Council, London.

Hollins, B & Pugh, S (1990) Successful Product Design: What to do and When Butterworths, London.

Hubka, V. (1982) Principles of Engineering Design Butterworths, London.

Hunt, VD. (1991) Enterprise Integration Sourcebook. The Integration of CALS, CE, TQM, PDES, RAMP & CIM Academic Press (Harcourt Brace Janovitch), San Diego.

Ingersoll Engineers (1989) Survey of Attitudes & Achievements in Products & Growth (May 1990) Ingersoll Engineers, Rugby.

Ingham, P. (1989) CAD in Mechanical and Production Engineering Heinemann Newnes: Oxford.

Johne, FA. (1991) New Style Product Development City University Business School Working Paper No. 121.

Johne, FA & Snelson, PA. (1987) Success Factors in New Product Development: A Selective Look at the Literature City University Business School, Working Paper No. 87, May. London.

Johne, FA & Snelson, PA. (1990) Successful Product Development. Strategies for High Growth from a Market Based Approach Blackwell, Oxford.

Joint Design Council - Engineering Council Working Party (1990) Attaining Competence in Engineering Design London.

Jones, DT. (1992) Leaner Enterprise Manufacturing Breakthrough 1(1) Jan-Feb.

Jones, JJ. (1970) Design Methods. Seeds for Human Futures Wiley, London.

Kelly, JE & Clegg, CW. (Eds) (1982) Autonomy & Control at the Workplace Croom Helm, London.

King, JR. (1985) The Management of Engineering Production: Fitting the Pieces Together Frances Pinter, London.

Langdon, R. (Ed) (1984) Design Policy: Design & Industry Design Council, London.

Langowitz, NS. (1989) Managing New Product Design and Factory Fit Business Horizons May-June, pp 76-79.

Lawrence, PR & Lorsch, JW. (1967) Organization and Environment Harvard Business School, Cambridge, MA.

Lawson, B. (1990) How Designers Think. The Design Process Demystified, 2nd Edition, Butterworth - Heinemann, Guildford.

Lee, GL. (1988) Managerial Strategies, Information Technology and Engineers In: Knights, D & Willmott, H. (Ed) New Technology & the Labour Process Macmillan, Basingstoke.

Lewis, JA; Pawar, KS & Riedel, JCKH. (1992) Competitive Benefits of CAD Use International Conference on Manufacturing Automation, University of Hong Kong, 10 - 12th August 1992, pp 686-690.

Lorenz, C. (1986) The Design Dimension. Product Strategy and the Challenge of Global Marketing Blackwell, Oxford.

Lucey, JJ. (1990) Developing and Introducing New Consumer Products Management Services 34(1) January pp 16-24.

Matousek, R. (1963) Engineering Design. A Systematic Approach Blackie & Sons, Glasgow.

Majchrzak, A. (1988) The Human Side of Manufacturing Automation Jossey Bass, San Francisco.

Majchrzak, A; Mosher, P & John, R. (1988) Technological Change & Structural Contingency Theory Unpublished Paper University of Southern California.

Majchrzak, A. (1990) Effect of CAD on the Jobs of Drafters and Engineers: A Quantitative Case Study International Journal of Man-Machines Studies 32 (3) March p245-262.

Majchrzak, A. (1990) The Human Side of Flexible Factory Automation: Suggestions for an Alternative Research Approach, In: Oskamp, S & Spacapan, S. (Eds) People's Reactions to Technology Sage, San Francisco.

Maropoulos, PG; Simmons, JEL & Sakkab, YY. (1990) Computer Aided Management of Threading Tools. In: Carrie, AS & Simpson, FI. (Eds) Advances in Manufacturing Technology V: Proceedings of the Sixth National Conference on Production Research 5-7th September 1990 (Strathclyde University: Glasgow) pp 126-130.

Medland, AJ. (1986) The Computer-based Design Process Kogan Page, London.

Medland, AJ & Burnett, P. (1986) CAD/CAM in Practice. A Managers Guide to Understanding & Using CAD/CAM Kogan Page, London.

Milburn, I. (1992) A Race Against Time Manufacturing Breakthrough: Managing Product Development. Special Issue on Simultaneous Engineering Jan/Feb, p15-19.

Mortimer, J & Hartley, J. (1991) Simultaneous Engineering. An Executive Guide Department of Trade & Industry, London.

National Economic Development Office (1979) Product Design A Report by K. G. Corfield, NEDO, London.

Northcott, J. (1986) Microelectronics in Industry. Promise & Performance Report No. 657, Policy Studies Institute, London.

Northcott, J & Rogers, P. (1984) Microelectronics in British Industry. The Pattern of Change Report No. 625, Policy Studies Institute, London.

Northcott, J & Walling, A. (1988) The Impact of Microelectronic Diffusion, Benefits and Problems in British Industry Research Report 673, Policy Studies Institute, London.

Oakey, RP; Rothwell, R & Cooper, S. (1988) The Management of Innovation in High Technology Small Firms. Innovation and Regional Development in Britain and the United States Pinter, London.

Oakey, RP; Thwaites, AT & Nash, PA. (1980) The Regional Distribution of Innovative Manufacturing Establishments in Britain Regional Studies 14 (3) p235-253.

Oakley, MH. (1978) The Torque Hose Actuator: A Study of the Development of a New Product PhD Thesis, University of Aston, Birmingham.

Oakley, MH. (1984) Managing Product Design Weidenfeld & Nicolson, London.

Oakley, MH. (Ed) (1990) Design Management. A Handbook of Issues & Methods Blackwell, Oxford.

Oakley, MH & Pawar, KS. (1982) The Design Production Interface: Guidelines for Developing Product Specifications Working Paper No. 245, The University of Aston Management Centre, Birmingham.

Olins, W. (ND 1985/6) The Wolff Olins Guide to Design Management. Mysteries of Design Management Revealed Design Council, London.

Owen, AE. (1982) Chips in Industry. An Overview of the Interaction & Implications of Microelectronics, Robots & Manufacturing Industry Economic Intelligence Unit, Special Report No. 135, London.

Pahl, G & Beitz, W. (Ed Wallace, K) (1984) Engineering Design Design Council - Pitman Press (original Springer Verlag 1977), London.

Pawar, KS & Oakley, MH. (1983) Researching the Design/Production Interface Design Studies 4.

Pawar, KS & Oakley, MH. (1982) Product Design and Development in Small Firms Design Studies 3.

Pawar, KS & Oakley, MH. (1982) Managing Product Design in Small Firms In: Design Policy Conference Proceedings, Design Council.

Pawar, KS (1985) An Investigation of the Nature of the Working Relationship Between Product Design and Production Functions in Manufacturing Companies PhD Thesis, University of Aston, Birmingham.

Pawar, KS & Riedel, JCKH. (1990) The Design Production Interface - A Survey. In: Carrie, AS & Simpson, FI. (Eds) Advances in Manufacturing Technology V: Proceedings of the Sixth National Conference on Production Research 5-7th September 1990 (Strathclyde University: Glasgow).

Pawar, KS; Riedel, JCKH. & Lewis, JA. (1991a) Management and Competitive Implications of CAD Use: The Case of the UK Mechanical Engineering Industry In: Li, M (Ed) Transformation of Science & Technology into Productive Power, Proceedings of the XIth International Conference on Production Research 18-23 August 1991, Hefei, Anhui, China (Taylor & Francis: New York & China Machine Press: Beijing) pp 289-292.

Pawar, KS; Riedel, JCKH. & Lewis, JA. (1991b) The Role of the Product Specification in Mechanical Engineering Design In: Spurgeon, D & Apampa, O. (Eds) Advances in Manufacturing Technology VI. P roceedings of the 7th Seventh National Conference on Production Research Hatfield Polytechnic, 3-5th September 1991, (Hatfield Polytechnic, Hatfield) pp137-141.

Pawar, KS; Glazzard, J & Forrester, P. (1991) The Team Re-design Approach to Improve Marketability and Manufacturability In: Management and New Production Systems, The Third International Production Management Conference on Management and New Production Systems Goteborg, Sweden, 27-28th May 1991 (European Institute for Advanced Studies in Management: Brussels).

Pawar, KS; Riedel, JCKH & Lewis, JA. (1991) Management and Competitive Implications of CAD Use: The Case of the UK Mechanical Engineering Industry. In: Li, M. (Ed) Transformation of Science & Technology into Productive Power. Proceedings of the 11th International Conference on Production Research, Hefei, Anhui, China, 18-23th August 1991, (Taylor & Francis: New York & China Machine Press: Beijing) pp 289-292.

Pawar, KS; Lewis, JA & Riedel, JCKH. (1992) Organising for New Product Introduction: The Case of the UK Mechanical Engineering Industry In: Karlsson, C. (Ed) International Product Development Management Conference on New Approaches to Development & Engineering, (European Institute for Advanced Studies in Management, Brussels) 18-19 May 1992, pp 469-485.

Pawar, KS; Menon, U & Riedel, JCKH. (1994) Time to Market Integrated Manufacturing Systems 5 (1) pp 14-23.

Pawar, KS & Riedel, JCKH. (1993) Management and Competitive Implications of CAD Use in the UK Mechanical Engineering Industry. Journal of Design and Manufacturing. Volume 3, pp 215-223.

Pawar, KS & Riedel, JCKH. (1993) Achieving Integration Through Managing Concurrent Engineering In: Hassard, JS; Forrester, PL; Hawksley, C & Tang, NKH. (Eds) International Conference on Managing Integrated Manufacturing. Organisation, Strategy & Technology Keele University, 22-24 September 1993 (Keele University: Keele) pp 381-399. (Also to be published in the International Journal of Production Economics, 1994)

Port, O; Sciller, Z; Miles, GL & Schulman, A. (1989) Smart Factories: America's Turn? A Few Advanced Plants Now - A Competitive Arsenal Soon. Special Report Business Week 8 May p64-69.

Potter, S; Roy, R; Capon, CH; Bruce, M; Walsh, V & Lewis, J. (1991) The Benefits and Costs of Investment in Design Design Innovation Group Report DIG-03 (Open University, Milton Keynes).

Pugh, S. (1990) Engineering Design - Unscrambling the Research Issues Journal of Engineering Design 1 (1).

Riedel, JCKH. (1989a) Sixth Month Progress Report. Wolverhampton Business School & School of Economics & Social Sciences, Wolverhampton Polytechnic.

Riedel, JCKH. (1989b) The Distribution of CAD/CAM in UK Manufacturing Industry Wolverhampton Business School & School of Economics & Social Sciences, Wolverhampton Polytechnic.

Riedel, JCKH. (1990) The Design - Production Interface in the UK Mechanical Engineering Industry: Transfer Progress Report Working Paper No. 1, Economics Division, Wolverhampton Business School, Wolverhampton Polytechnic.

Riedel JCKH. (1991a) A Review of the Findings of a Survey of Product Design Management in the UK Mechanical Engineering Industry Working Paper No. 3, Economics Division, Wolverhampton Business School, Wolverhampton Polytechnic.

Riedel, JCKH. (1991b) Case Studies of CAD Use in Mechanical Engineering Working Paper, Economics Division, Wolverhampton Business School, Wolverhampton Polytechnic.

Riedel, JCKH. (1991c) Case Studies of Product Design Management in Mechanical Engineering Working Paper, Economics Division, Wolverhampton Business School, Wolverhampton Polytechnic.

Riedel, JCKH; Lewis, JA; Pawar, KS & Syan, CS. (1990) A Survey of the Use of CAD in the UK Mechanical Engineering Industry In: McGeough, JA. (Ed) Sixth International Conference on Computer-aided Production Engineering London UK, 11-13th November 1990 (University of Edinburgh: Edinburgh).

Riedel, JCKH & Pawar, KS. (1990) Product Design Strategy and Manufacturing Strategy: Strategic Choice of Simultaneous Versus Sequential Engineering for the Introduction of New Products. In: Voss, C. (Ed) Manufacturing Strategy - Theory and Practice: Proceedings of the Fifth International Conference of the Operations Management Association UK Volume Two, Warwick University, 26-7 June 1990 (MCB University Press: Bradford).

Riedel, JCKH & Pawar, KS. (1991) The Strategic Choice of Simultaneous Versus Sequential Engineering for the Introduction of New Products. International Journal of Technology Management Special Issue on Manufacturing Strategy, Volume 6, Nos 3/4 pp 321-334.

Riedel, JCKH; Lewis, JA; & Pawar, KS. (1991) Competitive Product Design Strategies in the UK Mechanical Engineering Industry In: Bennett, D & Lewis, C (Eds) Achieving Competitive Edge. Getting Ahead Through Technology & People Proceedings of the Operations Management Association UK Sixth International Conference, Aston University UK, 25-26th June 1991 (Springer Verlag: London) pp 253-8.

Riedel, JCKH; Lewis, JA & Pawar, KS. (1992) Make or Buy: The Strategic Product Design Choice Integrated Manufacturing Systems Volume 3 No 2, pp9-14.

Riedel, JCKH & Pawar, KS. (1993a) Design & Production Integration: Tools, Techniques, Technology and Management Management & New Production Systems. Proceedings of the 4th International Production Management Conference, London Business School, 5-6 April 1993 (European Institute for Advanced Studies in Management: Brussels) pp 455-462.

Riedel, JCKH & Pawar, KS. (1993b) The Consideration of Production Aspects During Product Design and the Impact Upon Design Performance 9th International Conference on CAD/CAM, Robotics and Factories of the Future, New Jersey Institute of Technology, Newark, New Jersey, USA, 18-20 August 1993.

Riedel, JCKH & Pawar, KS. (1994 forthcoming) Strategies for Concurrent Engineering European Operations Management Association, First International Conference on Operations Strategy & Performance, Churchill College, Cambridge, 27-29 June 1994.

Rooney, J & Steadman, P. (1987) Principles of Computer-aided Design Open University/ Pitman, London.

Roy, R. (1984) Product Design and Innovation in a Mature Consumer Industry In: Langdon, R. (Ed) Design Policy: Design & Industry Design Council, London.

Roy, R; Potter, S; Rothwell, R & Gardiner, JP. (1990) Design and the Economy Design Council, London.

SAPPHO. (1976) Project SAPPHO - A Comparative Study of Success & Failure in Industrial Innovation Science Policy Research Unit, Sussex University, Brighton.

Sanderson, SW. (1989) Strategies for New Product Design & Product Renewal In: Hog, F (ed). Academy of Management Best Papers Proceedings of the 49th Annual Meeting.

Senker, P & Arnold, E. (1982) Designing the Future. The Implications of CAD: Interactive Graphics for Employment and Skills in the British Engineering Industry Engineering Industry Training Board Occasional Paper No.9, Watford.

Service, LM; Hart, SJ & Baker, MJ. (1988) Creating the Climate for Success. A Study of approaches and attitudes to product design and development in British Manufacturing Companies Department of Marketing, University of Strathclyde.

Service, LM; Hart, SJ & Baker, MJ. (1989) Profit by Design Design Council, London.

Shigley, JE & Mischke, CR. (Eds) (1990) Bearings & Lubrication. A Mechanical Designers' Workbook McGraw-Hill, New York.

Simmonds, P & Senker, P. (1989) Making More of CAD. A Report on a Longitudinal Study in British Engineering Companies Engineering Industry Training Board Report RC23, Watford.

Smith, M. (1986) UK Manufacturing: Output and Trade Performance Midland Bank Review Autumn, pp 8-16.

Smith, PG & Reinerstein, DG. (1991) Developing Products in Half the Time Van Nostrand Reinhold, New York.

Souder, WE. (1987) Managing New Product Innovations Lexington Books, Lexington, MA.

Stovey, RN. (1984) An Analysis of CAD/CAM Applications: With an Introduction to CIM Prentice-Hall, Englewood Cliffs, NJ.

Su, D & Swannell, MJ. (1993) Integrating CAD Packages into the Design & Manufacture of a Disc CAM, In: Hassard, JS; Forrester, PL; Hawksley, C & Tang, NKH. (Eds) International Conference on Managing Integrated Manufacturing, Organization, Strategy & Technology 22-24 September 1993, (Keele University: Keele) pp 511-515.

Subramanyam, S & Lu, S C-Y. (1991) Computer-aided Simultaneous Engineering for Components Manufactured in Small & Medium Lot Sizes Journal of Engineering for Industry 113 (4) November, p450-464.

Swift, KG. (1987) Knowledge Based Design for Manufacture Kogan Page, London.

Swords-Isherwood, N & Senker, P. (1980) Microelectronics & the Engineering Industry Frances Pinter, London.

Takeuchi, H & Nonaka, I. (1986) The New New Product Development Game Harvard Business Review 64 (1) Jan-Feb, pp 137-146.

Tidd, J. (1991) Flexible Manufacturing Technologies and International Competitiveness Pinter, London.

Tjalve, E. (1979) A Short Course in Industrial Design Newnes-Butterworth, London.

Topalian, A. (1980) The Management of Design Projects Associated Business Press, London.

Trygg, L. (1992) Simultaneous Engineering: A Movement or an Activity of the Few? International Product Development Management Conference on New Approaches to Development and Engineering, Brussels, 18-19th May 1992, European Institute for Advanced Studies in Management, Brussels, pp 569-582.

Twigg, D & Voss, CA. (1992) Managing Integration in CAD/CAM and Simultaneous Engineering. A Workbook Chapman & Hall, London.

Twiss, BC. (1977) Strategy & Planning for Production. In: Taylor, B & Sparkes, JR. Corporate Strategy & Planning Heinemann, London.

Ughanwa, DO. & Baker, MJ. (1989) The Role of Design in International Competitiveness Routledge, London.

Vora, PR & Helander, MG. (1992) A Review of Design Models and a Proposal for a Taxonomy of Design In: Helander, MG & Nagamachi, M. (Eds) Design for Manufacturability. A Systems Approach to Concurrent Engineering & Ergonomics Taylor & Francis, London.

Voss, CA, Russell, V & Twigg, D. (1991) Implementation Issues in Simultaneous Engineering International Journal of Technology Management Special Issue on Manufacturing Strategy, Volume 6, Nos 3/4, pp293-302.

Walsh, V; Roy, R & Bruce, M. (1988) Competitive by Design Journal of Marketing Management 4 (2) pp 201-216.

Walsh, V; Roy, R; Bruce, M & Potter, S. (1992) Winning by Design. Technology, Product Design & International Competitiveness Blackwell, Oxford.

Webb, DC; Baxter, RS & Bellingham-Smith, I. (1990) Problems of CAD-CAM Integration - An Industrial Case Study. In: Carrie, AS & Simpson, FI. (Eds) Advances in Manufacturing Technology V: Proceedings of the Sixth National Conference on Production Research 5-7th September 1990 (Strathclyde University: Glasgow) pp 302-306.

Whitney, DE. (1988) Manufacturing By Design Harvard Business Review Jul-Aug pp 83-91.

Williamson, O.E. (1975) Markets & Hierarchies. Analysis and Anti-trust Implications. A Study in the Economics of Internal Organization Free Press, New York.

Winch, G. (1988) The Implementation of CAD/CAM: Concepts & Propositions Warwick Papers in Management No. 24, Warwick University, September.

Woodward, J. (1980) Industrial Organisation 2nd Edition (original 1965), Oxford University Press, Oxford.

Yoshikawa, H & Warman, EA. (Eds) (1987) Design Theory for CAD North-Holland, Amsterdam.

Yu, G & Yule, DS. (1993) The Assimilation of Computer-Integrated Manufacturing & Concurrent Engineering. In: Hassard, JS; Forrester, PL; Hawksley, C & Tang, NKH. (Eds) International Conference on Managing Integrated Manufacturing. Organization. Strategy & Technology 22-24 September 1993, (Keele University: Keele) pp 401-412.

Zhang, Y & Mileham, AR. (1991) BEPPS-NC: An Automated Generator of NC Part Programs for Rotational Parts from CAD Product Model. In: Spurgeon, D & Apampa, O. (Eds) Advances in Manufacturing Technology VI. P roceedings of the 7th Seventh National Conference on Production Research Hatfield Polytechnic, 3-5th September 1991, (Hatfield Polytechnic, Hatfield) pp 11-15.

APPENDIX A

Terminology

BS	British Standard The British body responsible for setting and maintaining standards. eg. BS 5750 the standard for quality and BS 7000 product innovation standard.
CAD	Computer-aided design The capability of a computer to be used for automated industrial, statistical, biological, etc., design through visual devices.*1
CAM	Computer-aided manufacturing Manufacturing of products where the main production processes are pre-programmed and performed automatically.*1
CAD/CAM	Computer-aided design/computer-aided manufacturing Systematic combination of computer-aided design and computer-aided manufacture where - in principle - the design model could be transferred automatically into a respective manufacturing process. CAD and CAM systems are usually connected via a central data base.*1
CAE	Computer-aided engineering Automatic computing of problems related to the engineering realization of computer-aided designs.*1
CAPP	Computer-aided process planning Automatic computation of planning procedures for carrying out complex processes.*1
CIM	Computer-integrated manufacturing The integration of the major areas of manufacturing technology by a centralized, decentralized or distributed processing system. These areas are: design, storage and retrieval of information about the parts being manufactured (group technology, manufacturing resource planning), materials handling, control of CNC devices or single- purpose machinery and robots.*1
CNC-machine tool	Machine tool controlled by computer capable of carrying out complex operations in a manufacturing process.*1
CPU	Central Processor Unit. The actual processing/ calculating part (heart) of a computer.
DCF	Discounted Cash Flow A method for determining the pay back on an investment.
DEC	Digital Equipment Corporation The second largest (and American) computer manufacturer.
DFA	Design for Assembly A methodology for designing components so that they can be easily assembled.

DFM	Design for Manufacture A methodology for designing components to ease their subsequent manufacture.
DFS	Design for Service Designing a product to enable its easy servicing.
DFX	Design for X A methodology of deigning a product to take account of all the design for methodologies.
DIN	Deutsche Institut fur Normalisierung German standards body.
FEA FEM	Finite Element Analysis Finite Element Modelling The computational technique of analysing or modelling a solid object as a wire mesh grid. This can be used to calculate stress and weight distributions, fluid flow and heat transfer patterns.
FMS	Flexible manufacturing system Automated set of programmable machine tools operating in real time, controlled by a hierarchy of computers, linked by a materials- handling system that carries workpieces from one machine to the next and directed by a mainframe computer which is programmed to operate the tools in a specified sequence. Specialized soft- and hardware - CNC devices, robots - enable small quantity production, enhanced productivity and quality and create a more personal working atmosphere. Such systems can also run for hours without intervention.*1
GNC	Graphical Numerical Control A CNC programming package produced by the CAD Centre Ltd.
ibid	latin abbreviation meaning that this reference refers to the previous one - ie. they are the same.
IGES	Initial Graphical Exchange Specification A standard for the interchange of graphical information intended for human interpretation, eg. drawings and wire-frames. It is used for interchanging drawings between CAD, CNC and other such programs, however, the geometrical and machining information is absent and must be input manually or else separately transferred. PDES/STEP is better.
ISO	International Standards Organisation The international, as opposed to national, body for setting standards - such as for dimensions etc. eg. the ISO 9000 standard for quality.
MRP MRP I	Manufacturing Requirements Planning
MRP II	Manufacturing Resources Planning
OECD	Organisation for Economic Co-operation and Development An international organisation of the leading industrial countries.
PC	Personal Computer

PDES/STEP

Product Data Exchange Specification
An international standard for the exchange of product information. It goes beyond IGES by exchanging a complete product model and is intended for exchanging data between CAD/CAM systems.

QFD

Quality Function Deployment
A technique similar to TQM for identifying a department's customers and customer requirements. This is done for every department to build what is known as a house of quality - a specification of each department's customer requirements. This forms a matrix of the quality issues to be considered at each development stage and the performance of each with respect to the customer. QFD helps by ensuring a more formal definition of customers' requirements is drawn up at the specification stage. It thus clarifies the design more fully and earlier than usual. Having specified the customer requirements and the product requirements to meet them the analysis is projected forward to determine how the requirements can best be met.

TQM

Total Quality Management
A technique which for every function or department within a company identifies the customer for the department's goods or services and what the customer requirements are, and then aims to improve upon the quality of goods and services provided by the department.

2D

Two Dimensional
The representation of a component etc. graphically in two dimensions - using only x and y co-ordinates. Thus to produce a complete description of the component several views of it are required (at least two - elevation and plan/depth).

3D

Three Dimensional
A representation of a component etc. graphically in three dimensions - using x, y and z co-ordinates. A complete description of the geometry of the component can be thus produced. Two types of 3D graphical representation are in use Wire Frame and Solid Modelling.

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* Sources for the above:

1. Commission of the European Communities, 1986 p137-8.

The Product Design Process
Questionnaire Survey
WOLVERHAMPTON BUSINESS SCHOOL

Name and address of company at this site

Company Name	
Address	Tel
County	
Name of person responding *(Omit if anonymity desired)*	Position

Section 1 - Company Details

1 Main business carried out at this site ______________________

2 Please state the number of full-time employees:

at this site: __________ and in the whole company: __________

3 What is the "average" age of your production equipment:

please tick:

less than 5 years old ☐
6 - 10 years old ☐
11 - 30 years old ☐
older than 30 years ☐

4 What was the total annual sales turnover of the company for the last year:

year ending (1989) £ ______________ ('000s)

5 Please tick the dominant type of process technology in use:

One-off ☐ Batch ☐ Mass/flowline ☐

6 What is the period of time from inception to commercial introduction of a typical new product in your firm? ________ months ________ years

7 Please answer either part a) or part b) below:

a) How many new products does your company introduce each year? ____________

b) How often does your company introduce new products? _____ years _____ months

8 Please briefly describe the main products of your company and whether they are intermediate, final or consumer, below:

Section 2 - Design

9 Please supply a current organisation chart which shows the position of the design and production engineering functions within your company.

10 Does your company design the products it makes? Y ☐ N ☐
If your answer is *No* please go to question 32 in section 5 on page 6.

11 What elements of the Company's products are designed:
Please tick one or more as applicable

Design Type	in house	bought out	given by client
Engineering	☐	☐	☐
Aesthetic/Industrial	☐	☐	☐

12 Does your company have any of the following:
Please tick one or more as applicable

	None	On site	Other site
a Design department	☐	☐	☐
an R&D department	☐	☐	☐
a Development department	☐	☐	☐

13 Does your company use external design consultants? Y ☐ N ☐

Section 3 - Production Design Coordination

14 Is production-design co-ordination achieved by any of the following means?

please tick only one:

Simultaneous Engineering
(simultaneous design & engineering of product and process) ☐

Integrated product-process design department
(product design and process design/engineering personnel are located in the same department) ☐

Matrix Organisation
(separate product design and process engineering departments with personnel in each assigned to individual products) ☐

None ☐ **Other** ☐ *please specify* ____________________

15 Does your company use any of the following to co-ordinate between design and production for the introduction of new products?
Please tick one or more as applicable

Project team ☐

Product manager/champion ☐

Meetings ☐

Ad hoc visits/consultation between departments ☐

Liaison officer(s) ☐

Other ☐ *please specify* ____________________

15a Please circle the box of the most frequently used.

16 Please answer this question in relation to the previous question, Question 15.

Please tick the personnel involved:

- Designers ☐
- Design managers ☐
- Production engineering ☐
- Methods engineers ☐
- Production management ☐
- Finance ☐
- Marketing ☐
- Sales ☐
- R & D ☐
- General management ☐
- Others ☐ *please specify* ____________________

17 Are meetings held at which the progress of the design is reviewed? Y ☐ N ☐

18a Does the production (engineering) department have a say over any aspect of product design? Y ☐ N ☐

18b Does the production (engineering) department have a veto over any aspect of product design? Y ☐ N ☐

19 Is the product's design frozen when the design has reached a certain stage (ie. only essential engineering changes are made through a formal procedure)? Y ☐ N ☐

20 Does the company have formal, written design procedures? Y ☐ N ☐

21 Please indicate if standardisation of any of the following is considered in the design process:

- Drawings ☐
- Materials ☐
- Component ☐
- Dimensions/Tolerances ☐
- Fasteners ☐
- None ☐
- Others ☐ *please specify* ______________________

25 26 27 28 29

22 What percentage of components of the typical product are standard?

Please tick one:
0 - 20% ☐ 21 - 40% ☐ 41 - 60% ☐ 61 - 80% ☐ 81 - 100% ☐ 30

23 How would you classify the degree of coordination between design and production?

Please tick one:
Very good ☐ Good ☐ Neutral ☐ Bad ☐ Very bad ☐ 31

24a What in your opinion are the factors, if any, which hinder co-ordination between design and production?

Please tick :

- Departmental barriers ☐ 32
- Physical separation ☐ 33
- Bad personal relations ☐ 34
- Differing expectations ☐ 35
- Others ☐ *please specify* ______________________ 36 37 38

24b Please circle the box of the most important factor. 39

25a What in your opinion are the factors which would contribute to better co-ordination between design and production?

Please tick :

- No Departmental barriers ☐ 40
- Physical closeness ☐ 41
- Good personal relations ☐ 42
- Common expectations ☐ 43
- Others ☐ *please specify* ______________________ 44 45 46 47

25b Please circle the box of the most important factor.

Section 4 - Product Specification

26 Does your firm usually compile a product specification/design brief? Y ☐ N ☐ 48

If the answer is *No* please go to question 30, section 5.

27 Is the specification: Written ☐ Verbal ☐ or Both written & verbal ☐ 49

28a Which of the following aspects does the specification cover;

please tick those that apply:

Functional requirements	☐
Engineering design	☐
Styling/ appearance	☐
Product cost	☐
Development costs	☐
Project duration	☐
Production processes	☐
Production machinery	☐
Assembly techniques	☐
Labour requirements	☐
Compatibility with existing products	☐
Use of standardisation	☐
Materials	☐

50 51 52 53

28b Please circle the box of the most important aspect.

29 Please indicate the extent of involvement of the following personnel in drawing up the specification:

Degree of involvement *please tick one:*

Who	Extensive	Some	None	
Finance	☐	☐	☐	54
Marketing	☐	☐	☐	55
Sales	☐	☐	☐	56
Designers	☐	☐	☐	57
Design management	☐	☐	☐	58
Production engineering	☐	☐	☐	59
Production management	☐	☐	☐	60
R & D	☐	☐	☐	61
General management	☐	☐	☐	62
Customers	☐	☐	☐	63
Suppliers	☐	☐	☐	64
Others, *please specify:* ________	☐	☐	☐	65 66 67

LINE 1 2 3 | 3 4

Section 5 - Design Process

30 When are the following aspects considered in the design process:

Please tick :

Stage

Aspect	Conception	Detailed design	Prototype/testing	Pre-production	Production	
Product cost						5 6
Development costs						7 8
Functional requirements						9 10
Engineering design						11 12
Styling/ appearance						13 14
Standardisation						15 16
Production processes						17 18
Plant						19 20
Machinery						21 22
Assembly techniques						23 24
Labour requirements						25 26
Materials						27 28
Existing products						29 30
Production control						31 32
Product quality						33 34

31 What is the extent of involvement of production personnel in the design process?

Please tick one for each stage :

Stage	Extensive	Some	None	
Specification	☐	☐	☐	35
Development	☐	☐	☐	36
Detailed design	☐	☐	☐	37
Prototype	☐	☐	☐	38
Pre-production	☐	☐	☐	39

32 After the hand over of drawings from design to production please estimate, for the typical product, the number of components modified as a percentage (of total components); *please tick one:*

0 - 10% ☐ 11 - 20% ☐ 21 - 30% ☐ 31 - 50% ☐ 40

51 - 70% ☐ 70 - 100% ☐

Section 6 - Computer Aided Design

33 Does your company have access to CAD? Y ☐ N ☐ 41
If not please turn to the last page.

34 When the company first used the CAD system did it:

please tick one:

transfer all design work onto it ☐
do only new products ☐
transfer proportion of old & new designs onto it ☐ 42

34a And did the company input a database of existing parts? Y ☐ N ☐ 43

35 Do you use a database of standard components (with standard dimensions) on the CAD system? Y ☐ N ☐ 44

36 Are production engineering able to make design changes using the CAD system?

Please tick one:
View only ☐ Change ☐ No ☐ 45

37 Please detail what you use CAD for;

Please tick those that apply

Drafting: 2D ☐ 3D ☐ solid modelling ☐ 46 47 48
Parts list/BOM ☐
NC, CNC programming: 3 axis ☐ 5 axis ☐ 49
Die & tool design ☐ 50
Tool path nesting ☐
Finite Element Analysis ☐
Simulate CNC machining: 3 axis ☐ 5 axis ☐
Component interference checking ☐
Design for assembly ☐
Design for automatic assembly ☐ 51 52
Expert system usage ☐
Mechanical, kinematic design ☐
Other ☐ 53 54
please specify ______________________________

38 In which design stage(s) is CAD used:

please tick those stages which apply

Conception	☐	Pre-production	☐
Specification	☐	Prototype	☐
Feasibility	☐	Testing	☐
Development	☐	Production	☐
Detailed design	☐		

55 56 57 58

As a result of the use of CAD:

39 How has coordination between design and production changed due to the use of CAD? *Please tick one:*

very much increased ☐ increased ☐ no change ☐ reduced ☐ very much reduced ☐ 59

40 How has integration between design and production changed due to the use of CAD?

Please tick one:

very much increased ☐ increased ☐ no change ☐ reduced ☐ very much reduced ☐ ☐ 60

41 Please state the benefits of CAD that you have ***achieved:***

- shortened lead-time from initial stage to commercialisation ☐
- rapidity of design ☐
- allows shorter production runs ☐
- ease of modification ☐
- greater customisation of product ☐
- increase sophistication of product ☐
- simplify assembly ☐
- simplify / ease manufacture ☐
- increased consideration given to manufacture of product ☐
- others, ☐

please specify ______________________

☐☐☐☐ 61 62 63 64

☐☐ 65 66

41a Please circle the box of the most important benefit. ☐ 67

END OF QUESTIONNAIRE.

Thank you for your time and attention in filling out this questionnaire. If you have any queries about the research programme please do not hesitate to contact me, at the address below.

Please tick if you wish to receive a summary report of the results ☐ ☐ 68

Would you be prepared to discuss the questionnaire at a later stage? Y ☐ N ☐ ☐ 69

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APPENDIX C

Research Project Output

The following table is a quantitative summary of the publications, related to the research project on the design - production interface. The project started in October 1988 and terminated in this PhD thesis in January 1994.

Thesis	1
Journal Articles	5
International Conf Papers	10
National Conf Papers	2
Total Conferences	12
Teaching Cases	1
Working Papers	8
Total Publications	22
Average/year	5.5

Also a book is in preparation on concurrent engineering, which is approximately half complete.

Publications List

Journal Articles

Pawar, KS; Menon, U & Riedel, JCKH. (1994) Time To Market Integrated Manufacturing Systems Volume 5, No 1, pp 14-23.

Pawar, KS & Riedel, JCKH. (1994, forthcoming) Achieving Integration Through Managing Concurrent Engineering International Journal of Production Economics.

Pawar, KS & Riedel, JCKH. (1993) Management and Competitive Implications of CAD Use in the UK Mechanical Engineering Industry Journal of Design and Manufacturing Volume 3, pp 215-223.

Riedel, JCKH; Lewis, JA & Pawar, KS. (1992) Make or Buy: The Strategic Product Design Strategy Integrated Manufacturing Systems Volume 3, No. 2, pp 9-14.

Riedel, JCKH & Pawar, KS. (1991) The Strategic Choice of Simultaneous Versus Sequential Engineering for the Introduction of New Products International Journal of Technology Management Special Issue on Manufacturing Strategy, Volume 6, Nos. 3/4, pp 321-334.

Teaching Materials

Pawar, KS & Riedel, JCKH. (1993) Simultaneous Engineering, a Strategic Choice Teaching Case Study No. 693-001, European Case Clearing House, Cranfield.

Conference Papers

Pawar, KS & Riedel, JCKH. (1993) Achieving Integration Through Managing Concurrent Engineering In: Hassard, JS; Forrester, PL; Hawksley, C & Tang, NKH. (Eds) International Conference on Managing Integrated Manufacturing. Organisation, Strategy & Technology, Keele University, 22-24 September 1993 (Keele University: Keele) pp 381-399.

Riedel, JCKH & Pawar, KS. (1993) The Consideration of Production Aspects During Product Design and the Impact Upon Design Performance 9th International Conference on CAD/CAM, Robotics and Factories of the Future, New Jersey Institute of Technology, Newark, New Jersey, USA, 18-20 August 1993.

Riedel, JCKH & Pawar, KS. (1993) Design & Production Integration: Tools, Techniques, Technology and Management Management & New Production Systems. Proceedings of the 4th International Production Management Conference, London Business School, 5-6 April 1993 (European Institute for Advanced Studies in Management: Brussels) pp 455-462.

Lewis, JA; Pawar, KS & Riedel, JCKH. (1992) Competitive Benefits of CAD Use Proceedings of the International Conference on Manufacturing Automation, Hong Kong, 10-11th August 1992 (University of Hong Kong: Hong Kong) pp 686-690.

Pawar, KS; Lewis, JA & Riedel, JCKH. (1992) Organising for New Product Introduction: The Case of the UK Mechanical Engineering Industry. In: Karlsson, C. (Ed) International Product Development Management Conference on New Approaches to Development and Engineering, Brussels, 18-20 May 1992 (European Institute for Advanced Studies in Management: Brussels) pp 469-485.

Pawar, KS; Riedel, JCKH & Lewis, JA. (1991) The Role of the Product Specification in Mechanical Engineering Design In: Spurgeon, D & Apampa, O. (Eds) Advances in Manufacturing Technology VI. Proceedings of the Seventh National Conference on Production Research, Hatfield Polytechnic, 3-5th September 1991 (Hatfield Polytechnic, Hatfield) pp 137-141.

Pawar, KS; Riedel, JCKH & Lewis, JA. (1991) Management and Competitive Implications of CAD Use: The Case of the UK Mechanical Engineering Industry. In: Li, M. (Ed) Transformation of Science & Technology into Productive Power. Proceedings of the 11th International Conference on Production Research, Hefei, Anhui, China, 18-23th August 1991, (Taylor & Francis: New York & China Machine Press: Beijing) pp 289-292.

Riedel, JCKH; Lewis, JA & Pawar, KS. (1991) Competitive Product Design Strategies in the UK Mechanical Engineering Industry. In: Bennett, D & Lewis, C. (Eds) Achieving Competitive Edge. Getting Ahead Through Technology & People; Proceedings of the Sixth International Conference of the Operations Management Association UK, Aston University, 25-26th June 1991 (Springer Verlag: London) pp 253-258.

Riedel, JCKH & Pawar, KS. (1990) Product Design Strategy and Manufacturing Strategy: Strategic Choice of Simultaneous Versus Sequential Engineering for the Introduction of New Products. In: Voss, C. (Ed) Manufacturing Strategy - Theory and Practice: Proceedings of the Fifth International Conference of the Operations Management Association UK. Volume Two, Warwick University, 26-27th June 1990 (MCB University Press: Bradford) pp 667-678.

Riedel, JCKH; Lewis, JA; Pawar, KS & Syan, CS. (1990) A Survey of the Use of CAD in the UK Mechanical Engineering Industry In: McGeough, JA. (Ed) Sixth International Conference on Computer-aided Production Engineering. London, 11-13th November (University of Edinburgh) pp 323-328.

Pawar, KS & Riedel, JCKH. (1990) The Design Production Interface - A Survey. In: Carrie, AS & Simpson, FI. (Eds) Advances in Manufacturing Technology V: Proceedings of the Sixth National Conference on Production Research 5-7th September 1990 (Strathclyde University: Glasgow) pp 13-17.

Proposed Conference Papers

Riedel, JCKH & Pawar, KS. (1994) Strategies for Concurrent Engineering European Operations Management Association, First International Conference on Operations Strategy & Performance, Churchill College, Cambridge, 27-29 June 1994.

Working & Discussion Papers

Riedel, JCKH. (1989a) Sixth Month Progress Report. Wolverhampton Business School & School of Economics and Social Sciences, Wolverhampton Polytechnic.

Riedel, JCKH. (1989b) The Distribution of CAD/CAM in UK Manufacturing Industry Wolverhampton Business School & School of Economics and Social Sciences, Wolverhampton Polytechnic.

Riedel, JCKH. (1990) The Design - Production Interface in the UK Mechanical Engineering Industry: Transfer Progress Report Working Paper No. 1, Economics Division, Wolverhampton Business School, Wolverhampton Polytechnic.

Riedel, JCKH; Pawar, KS & Lewis, JA. (1991) Management and Competitive Implications of CAD Use in the Mechanical Engineering Industry. Working Paper No. 5, Economics Division, Wolverhampton Business School, Wolverhampton Polytechnic.

Riedel JCKH. (1991a) A Review of the Findings of a Survey of Product Design Management in the UK Mechanical Engineering Industry Working Paper No. 3, Economics Division, Wolverhampton Business School, Wolverhampton Polytechnic.

Riedel, JCKH. (1991b) Case Studies of CAD Use in Mechanical Engineering Working Paper, Economics Division, Wolverhampton Business School, Wolverhampton Polytechnic.

Riedel, JCKH. (1991c) Case Studies of Product Design Management in Mechanical Engineering Working Paper, Economics Division, Wolverhampton Business School, Wolverhampton Polytechnic.

Pawar, KS; Riedel, JCKH. & Lewis, JA. (1991) The Product Specification in Mechanical Engineering Design Working Paper No. 6, Economics Division, Wolverhampton Business School, Wolverhampton Polytechnic.

Other Publications

Pawar, KS; Glazzard, J & Forrester, P. The Team Re-design Approach to Improve Marketability and Manufacturability Third International Production Management Conference on Management and New Production Systems, Goteborg, Sweden, 26-29th May 1991.

Pawar, KS (1985) An Investigation of the Nature of the Working Relationship Between Product Design and Production Functions in Manufacturing Companies PhD Thesis, University of Aston.

Presentations/ Seminars

External Seminars

Business Research Institute, Aston Business School CAD/CAM - The Sequel 25 October 1990, Aston University.

Internal Seminars

Research Degrees Programme, Wolverhampton Business School Product Design Strategy 15 March 1990, Wolverhampton Polytechnic.

Economics Division Research Seminar, Wolverhampton Business School CAD in the UK Mechanical Engineering Industry 20 November 1990, Wolverhampton Polytechnic.

Research Degrees Programme, Wolverhampton Business School Competitive Implications of CAD in the UK Mechanical Engineering Industry 12 February 1991, Wolverhampton Polytechnic.

Research Degrees Programme, Wolverhampton Business School The Interaction Between Survey and Case Study Methods 4 June 1991, Wolverhampton Polytechnic.

Research Degrees Programme, Wolverhampton Business School The Application of Theory to Research Data 21 January 1992, Wolverhampton Polytechnic.

APPENDIX D

CAD Statistical Appendix

PSI Microelectronics in Manufacturing Industry Survey

The statistics listed in the tables below refer to microelectronics applications in production processes which are already in production. The weighted figures given for UK manufacturing refer to manufacturing establishments which have more than 20 employees, except where shown otherwise in some tables.

Reliability of the PSI Survey

The PSI survey is a biannual survey of use of microelectronics of manufacturing establishments. Over the six year period 1981 to 1987 there have been four surveys. Each survey attempts to use the same establishments as were used in the previous survey. This is necessary so that comparisons for increases of use etc. can be made across surveys and thus over the years. This can only be done if the same establishments are surveyed.

Three measures can be used to judge the reliability of the PSI survey on this issue. Firstly, the refusal rate of firms to be included in the survey in any one year (Table A). Secondly, the drop out rate of firms of a previous survey in the following survey (Table B). Thirdly, the percentage of the previous survey included in the following year (Table C). Note that measures B and C will be different because changes in size of factories and industrial structure in between surveys necessitate the including of new firms into the survey (Northcott & Walling, 1988 p192, 251).

Table A: PSI Refusal Rate

Year	1983	1985	1987
Refusal Rate	12%	5.8%	10.3%

Table B: PSI Drop Out Rate

% of previous survey not in current one

%'81 not in '83	%'83 not in '85	%'85 not in '87
-	9.4	11.6

Table C: Respondents Included from previous PSI Surveys

%'81 in '83	%'83 in '85	%'85 in '87
77.8	84.8	76.3

Table A shows that the refusal rate is around 10% for each survey. This would be similar to the refusal rate for any telephone questionnaire. The drop out rate is also around 10%. The reasons for firms dropping out of the survey were given as (figures for 1987): refusals, bankruptcies (1.8%), change of size and/or industry of establishment, cessation of manufacture (0.6%), moved away (3.3%), employment fell below 20 (1.3%), and various reasons/ unavailable in an unbiased way. Table C shows that approximately three-quarters of the previous survey are included in the current one. Thus of the original sample in 1981 50.3% are included in the 1987 survey. This provides reasonable grounds for drawing comparisons across the years.

A further issue in the reliability of the PSI is its degree of coverage of manufacturing establishments. This is particularly the case as surveys up until 1987 excluded firms with less than 20 employees. These firms account for 69% of manufacturing establishments but only 8% of employment (Northcott & Rogers, 1984 p198). Thus the PSI survey on this basis of employment coverage can be said to be representative of manufacturing establishments.

Table 1: Extent of Use of Microelectronics

Year	1981	1983	1985	1987
Sample Establishments	34	55	68	77%
All UK Manuf. Estabs.(>20 empees.)	18	37	49	59%

(Source: Northcott, 1986 p2-3; Northcott & Walling, 1988 p30-1)

Table 2: Usage of Microelectronics by Employment Size

Year	20-49	50-99	100-199	200-499	500-999	1000-	1-19
1981	8	18	25	32	48	75%	
1983	24	32	47	57	78	91%	
1985	35	44	66	79	92	96%	
1987	45	60	74	89	94	99%	18%

(Source: Northcott & Walling, 1988 p129)

Table 3: Usage of Microelectronics by Industry

Yr	Food drink	Chems metals	Mech eng.	Elec eng.	Vehi-cles	Metal goods	Tex-tiles	Clot-hing	Paper print	Other
1981	38	41	35	48	46	28	18	13	44	27%
1983	71	60	59	61	64	51	40	31	65	43%
1985	80	75	70	79	70	60	52	48	78	57%
1987	85	83	76	84	75	72	65	62	86	67%

(Source: Northcott & Walling, 1988 p137)

Table 4: Usage of Microelectronics by Region

Yr	Scot-Land	North	Yorks Hmbr	North West	East Mid	West Mid	East Ang	South East	South West	Wales
1981	28	40	28	33	27	32	28	40	51	33%
1983	65	66	54	55	54	49	52	54	68	42%
1985	73	75	70	70	69	58	77	68	70	63%
1987	76	75	83	81	76	70	81*	76	75	89%*
Base No.										
1987	100	69	97	151	110	162	36	326	114	35

*These high rates are misleading due to the small number of applications.

(Source: Northcott & Walling, 1988 p141)

Table 5: Usage of Microelectronics in Design

Year	1983	1985	1987
Sample Establishments	14	22	33%
All UK Manuf.	6	12	17%

(Source: Northcott & Walling, 1988 p63,147-8)

Table 6: Usage of Microelectronics in Design by Employment Size

Yr	1-19	20-49	50-99	100-199	200-499	500-999	1000-	Total
1983	-	11	11	14	20	25	38	23%
1985	-	6	9	14	21	33	49	22%
1987	5	10	14	21	36	52	69	33%

(Sources: Northcott & Rogers, 1984 p161; Northcott, 1986 p131; Northcott & Walling, 1988 p149 respectively)

Note: The apparent discrepancy between the figures for 1983 and 1985, the former being larger than the latter, is accounted for by the figures for 1985 onwards being for microelectronics applications already in commercial operation. The 1983 figures include factories in the early stages of development and not yet in production.

Table 7: Usage of Microelectronics in Design by Industry

Yr	Food drink	Chems metals	Mech eng.	Elec eng.	Vehicles	Metal goods	Textiles	Clothing	Paper print	Other
1983	5	17	27	47	51	17	21	21	11	10%
1985	10	18	31	48	43	12	12	5	13	9%
1987	17	30	50	63	64	14	22	11	21	20%

(Sources: Northcott & Rogers, 1984 p161; Northcott, 1986 p131; Northcott & Walling, 1988 p150 respectively)

Table 8: Usage of Microelectronics in Design by Region

Yr	Scot-Land	North	Yorks Hmbr	North West	East Mid	West Mid	East Ang	South East	South West	Wales
1983	28	17	18	25	30	22	13	22	33	15%
1985	13	29	14	20	24	21	25	24	31	12%
1987	27	35	29	34	34	32	33	35	40	31%

(Sources: Northcott & Rogers, 1984 p161; Northcott, 1986 p131; Northcott & Walling, 1988 p150 respectively)

Table 9: Usage of CAD Workstations

Year	1983	1985	1987
Sample Establishments	10	17	31%
All UK Manuf.		7	17%

(Source: Northcott & Walling, 1988 p151)

Table 10: Number of CAD Workstations in UK

Year	1983	1985	1987
No.Stations ('000) (Weighted UK Manuf)	9	11	21

(Source: Northcott & Walling, 1988 p152)

Table 11: Number of CAD Workstations per User Establishment

		Number of CAD Workstations				
Year	No.User Estabs	1	2-10	11-50	50-	Average No.
1983	117	33%	54	12	1	8
1985	185	26%	57	16	1	6
1987	355	27%	56	15	2	9

(Source: Northcott & Walling, 1988 p152)

Table 12: Establishments Using CAD Workstations by Size

Year	1-19	20-49	50-99	100-199	200-499	500-999	1000-
1983		3	4	7	8	12	28%
1985		4	4	7	16	23	48%
1987	4	10	13	19	36	49	61%

(Source: Northcott & Walling, 1988 p155)

Table 13: Number of CAD Workstations in Use by Size

Year	1-19	20-49	50-99	100-199	200-499	500-999	1000-
	Thousand Workstations (Weighted for UK)						
1983		2	1	1	1	1	4
1985		1	1	1	2	1	4
1987	2	3	3	3	4	2	5

(Source: Northcott & Walling, 1988 p155)

Table 14: Usage of CAD Workstations by Industry

Yr	Food drink	Chems metals	Mech eng.	Elec eng.	Vehi-cles	Metal goods	Tex-tiles	Clot-hing	Paper print	Other
1983	7	8	8	26	27	5	8	3	10	3%
1985	11	13	22	36	40	6	3	4	13	7%
1987	17	31	41	52	58	17	22	20	19	19%

(Source: Northcott & Walling, 1988 p156)

Table 15: Number of CAD Workstations by Industry ('000)

Yr	Food drink	Chems metals	Mech eng.	Elec eng.	Vehi-cles	Metal goods	Tex-tiles	Clot-hing	Paper print	Other
1983	1	0	1	3	1	1	0	0	2	0
1985	0	0	1	3	1	0	0	0	2	0
1987	1	1	3	6	4	1	1	1	3	1

(Source: Northcott & Walling, 1988 p156)

Table 16: Usage of CAD Workstations by Region

Yr	Scot-Land	North	Yorks Hmbr	North West	East Mid	West Mid	East Ang	South East	South West	Wales
1983	9	8	8	13	9	8	4	12	24	6%
1985	17	21	11	17	14	16	15	18	24	16%
1987	29	30	25	33	37	25	22	34	34	31%

(Source: Northcott & Walling, 1988 p156)

Table 17: Number of CAD Workstations by Region ('000)
Extent of Use of CAD Workstations

Yr	Scot-Land	North	Yorks Hmbr	North West	East Mid	West Mid	East Ang	South East	South West	Wales
1983	0	0	1	1	0	1	0	4	1	0
1985	1	1	0	1	0	2	0	2	1	0
1987	1	1	1	3	3	2	0	6	3	1

Table 18: Extent of Use of CAD Workstations 1987
Extent of Use of Microelectronics in Design

	% of Products			% of Processes			
	1-10	11-50	51-100	1-10	11-50	51-100	
No. Users	88	74	57	265	436	179	
CAD Users all estabs.	48	60	68%	29	48	39%	
No.CAD Stations (UK Weighted)	2	2	4	5	12	3	('000)
Design	59	69	83%	37	50	38%	

(Source: Northcott & Walling, 1988 p155,149)